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Investigating the Heterogeneity of Economic Convergence in Latin America Countries-An Econometric Analysis of Systems of Regression Equations

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Abstract

For a selected group of Latin America countries we estimated the parameters of convergence equations on the basis of annual data. We test cross-country heterogeneity of parameters within a system of Seemingly Unrelated Regression Equations (SURE) that departures from standard approach utilizing panel regressions. We show empirical evidence in favor of the variability of parameters describing the convergence effect and productivity growth rates across analyzed club of countries. We also test several restrictions leading to less parameterized models imposing constancy of parameters of interest across countries.

Keywords: convergence; labour productivity; economic growth; SURE, Latin America

JEL classification: C30, C047

Introduction

The convergence hypothesis derived from the Solow model and its diminishing returns to capital concept (Solow, 1956) is a classical topic of the theory of economic growth. The implications of a concave down increasing production function- which serves as the basis for neoclassical growth-models - are straightforward. The slope of the function is positive, but decreases as the amount of allocated production factors increases. Hence the returns on capital will be lower over time and will lead to a more effective allocation of investment above a certain level, most probably to another country. Whether this phenomenon takes place in real life is a crucial topic for convergence research.

Usually convergence is defined in two types; beta and sigma convergence. If a country with lower initial per capita income achieves faster growth than a richer one, we speak about beta convergence. Furthermore, beta convergence can be analysed in a conditional manner by setting stable some parameters (investment rate, government expenditures and other) or in an absolute manner without constant variables. The beta hypothesis has been broadly discussed among researchers (Barro and Sala-i-Martin, 1990, 1992; Romer, 1989; Islam, 1995; Martin & Sanz, 2003; Mathur, 2005; Rapacki and Próchniak 2009; Siljak, 2015). Sigma convergence has also been widely discussed (Ingo, 1995; Slaughter, 1997; Drennan, Lobo and Strumsky, 2004; Dvorkova, 2014). Complementary to beta convergence, sigma convergence verifies whether the income gap between the poorer and the richer country has declined over time. Hence beta convergence is a necessary, but not sufficient condition for sigma convergence (Young, Higgins and Levy, 2008).

While the existence and the magnitudes of the convergence speed are broadly discussed, there are no conclusions. Barro and Sala-I-Martin (1992) found a close beta convergence of 2% among the economies, but current research found a much higher rate especially among Central & Eastern European countries (Próchniak, 2011) or no convergence at all in the less developed countries (Kumo, 2011). Despite the lack of a common magnitude, there are also areas in the world not investigated widely by convergence researchers.

Hopenhayn and Neumeyr (2004) investigated the historical development of South American countries in relation to the United States. They concluded, that there is a huge gap between the US and South American countries, since the latter did not experience sustainable growth and have reached their last per capita income peak in the 1970s. Furthermore, between 1960 and 1985, 74% of economic growth was based on physical capital, making it twice of the world's average. Solimano and Soto (2005) also analysed the growth potential and determinants in South America. Despite a small average annual GDP per capita growth rate of 1.6%, they found a huge variance between analysed countries, both in the levels of GDP and its growth rates. Another remarkable finding was that fast developing nations in the period of 1960-1980 i.e. Mexico and Brazil, grew much slower in the period of 1980-2002. Even today we may still find huge disparities between the specific countries. For example, the average 2014 GDP per capita for 12 Latin American countries was equal to 15,140 USD. But, the average is a result of huge difference between nations: the wealthiest, Curacao with 25,964 USD and the poorest, Bolivia with 6,012 USD. These income differences make South America an interesting subject for research of the convergence hypothesis.

The purpose of this article is to utilise a novel framework for convergence testing which may serve as a substitute of panel regression techniques. The model is built in the econometric environment of the Seemingly Unrelated Regression Equations (SURE) system, initially developed by Arnold Zellner; see e.g. Zellner (1962). The idea was previously applied by Pipień and Roszkowska (2018) for convergence analysis of countries from the Commonwealth of Independent States (CIS) and Central & Eastern Europe (CEE) and also by Olszak and Pipień (2016) to the problem of procyclicality of the financial system. The methodology departs from commonly adopted regression analysis and enables detailed insight into heterogeneity of the speed of convergence and other effects among countries. By recalling a very interesting generalisation of the simple linear regression (SURE), we provide an econometric framework to verify the fundamental question, whether convergence seems to be a country-specific phenomenon rather than an attribute of a much broader area like region, continent or the group of countries researched for this article.

The dataset consists of macroeconomic indicators for 10 Latin American countries from 1954 to 2014. The indicators used for the explanatory variables vector include investment rates, government consumption, inflation and others.

The article is structured as follows: Section 2 reviews the literature about convergence in Latin America, in section 3 the econometric model used for the analysis is introduced, section 4 describes the results and finally section 5 concludes with final inference.

Economic convergence in Latin America - literature overview

The quest for empirical evidence supporting the convergence hypothesis in case of Latin American countries was subject to many studies. This region of emerging economies, that rapidly grew during last couple of decades received a lot of attention, when analyses of economic processes were of primary importance. The empirical literature related to convergence may be organised in three broad streams depending on the econometric approach applied in research. Two primary streams use either panel regression techniques or time series methods, with the latter focusing on integration approach and testing of unit roots. The third stream contains unique alternatives or non-standard departures from both panel regression and standard time series econometrics. Some Authors, like Quah (1993, 1996, 1997) refer to the sigma convergence tests as a separate topic, but an overview presented here does not follow this viewpoint.

Convergence tested within panel regression scheme

Ferreira (2000) investigated the sigma and beta convergence for Brazil. Using cross-sectional data, the absolute beta convergence was confirmed and the approximated speed of convergence was 1% during the whole period from 1970 to 1995. In the analysed models Ferreira (2000) included some variables like investment or schooling rate to verify the conditional convergence process, The resulting speed of convergence ranged from 3% in the whole analysed period 1970-1995 and 7% in sub-period of the 1970's. Ferreira (2000) put a lot of attention on the income inequality problem across the domestic regions. For example, in 1995 the per capita income for the whole country was about seven times higher than in the case of the poorest regions and twice lower when compared to the richest district in Brazil. There was a reduction of the income inequalities observed through decades as the Theil's index declined from 0.216 in 1970 to 0.116 in 1995. This would support the hypothesis about the existence of sigma convergence among Brazil's regions Ferreira (2000) .

For Bolivia, the income convergence hypothesis was analysed by Kuscevic and Río Rivera (2014). Panel data consisting of observations of economic performance of regions in Bolivia in the period 1988-2011 was set as the dataset. The beta convergence was verified on the basis of the model of linear regression, while Herfindahl/Hirschman index with the sample standard deviation was used for verification of the sigma convergence. Kuscevic and Río Rivera (2014) built three different regression equations to test the beta convergence. The resulting speed of beta convergence among Bolivian regions ranged between 4% and 7.2%. The evidence in favour of sigma convergence was confirmed only for the period from 1988 to 1992, when the sample standard deviation reached 0.24 (in 1988) to 0.2 (in 1992). Afterwards the substantial income disparities diverged until 1997, and since then remained relatively stable, at the level 0.3 in 2010. Kuscevic and Río Rivera (2014) indicated the strong heterogeneity of economic development among regions in Bolivia as the main source of great uncertainty about empirical importance of convergence processes. Excluding the Tarija region from the analysis, a strong sigma convergence pattern could be observed from 2000, with sample standard deviation of 0.3, to 2010 characterized by the sample standard deviation at the level of 0.18.

There is also vast amount of papers reporting non-existence of the convergence process for Latin America; see e.g. Dobson and Ramlogan (2002a). The Authors analysed 19 countries and their economic performance during the period 1970-1998. The estimated speed of convergence was not statistically significant. When analysing sub-periods, only in the interval from 1970 to 1980 statistically significant estimates were reported. Dobson and Ramlogan (2002a) assessed the speed of convergence in the 1970's at the level of 1.5%. Also the conditional convergence (including population size) was not empirically supported for the entire period. But again, for the 1970's, a statistically significant beta coefficient was estimated at the level of 0.3%. For the 1990's Authors reported negative point estimates. From 1980 to 1998 the income disparities increased by 5.6%. A slight local decrease was observed only in the period from 1976 to 1988. This variability of income inequalities seems to be the main reason for the non-existence of the sigma convergence.

Sutton et al. (2006) investigated the absolute and conditional convergence between 6 Latin American countries analysing the period from 1970 to 2001. There was nearly no evidence for the absolute convergence within the analysed region. Augmenting the regression equation with some regional dummies, the convergence speed increased, especially in case of Peru (3.1%), Brazil (2.7%) and Chile (1.7%).The sample standard deviation did not decline at all for the whole analysed period, precluding the sigma convergence effect. Until the 1990s a small decline could be reported, but after the implementation of trade reforms, countries like Argentina, Brazil, Colombia, Mexico and Peru were characterized by an increase of disparities.

Dobson and Ramlogan (2002b) revisited the problem of testing the existence economic convergence. Estimating parameters of corresponding growth regression for 19 Latin American countries, they extended the analysed time period from 1960 to 1990. They also added a dummy for oil production together with sectoral composition. Authors also utilised information about population growth, savings rate and human capital. The absolute beta convergence for the whole period was supported. The estimated speed of convergence reached the value 0.45% but was statistically insignificant. In the model with the oil production dummy variable, for nearly all periods (despite 1960-1965 and 1985-1990) the convergence hypothesis was supported, with a reported pooled estimate of speed of convergence at the level of 0.65%. Including some other dummy variables and other regressors resulted in the increase of estimated speed of convergence (1%) but statistical insignificance of estimates was still the most important element arising from the analyses.

Convergence tested within time series models

An interesting approach was undertaken by Sanz-Villarroya (2005). Contrary to majority of empirical investigations, where similar countries or regions within a country are compared, the Author verified the convergence hypothesis of Argentina with respect to Canada and Australia. Time series techniques with tests of existence of the unit roots of Perron (1989) were applied. Empirical results indicated that Argentina was catching-up to Australia only until 1899 and to Canada until 1896. Starting from the 20th century, Argentina's economic progress started to fall behind both countries. After 1975, Canada and Australia started to diverge. Finally a comparison with the OECD countries was performed, which showed that in 1913 Argentina started to diverge from the OECD which was similar to other findings; see Taylor (1992).

King and Ramlogan (2008) investigated whether 18 Latin American countries were catching-up to the United States. The dataset used in research covered the post-war period, namely from 1950 to 2000. Authors performed unit root tests on productivity series. The absolute beta convergence didn't find any support. Only Chile converged on a statistically significant level. Galvao and Gomes (2007) also searched for empirical evidence for existence of the beta convergence across 19 Latin American countries on the basis of series covering the period from 1951 to 1999. In case of 12 countries, convergence was empirically verified, while seven countries diverged. In the set of these seven divergent countries, five were from South America. Hence Galvao and Gomes (2007) divided their analyses and focused on Central and South Latin America separately. They reported that all Central countries were subject to convergence except El Salvador. Authors found their results surprising, because Dobson and Ramlogan (2002a) didn't confirm the convergence for nearly the same group of countries.

Attempts to generalize standard econometric approaches of testing the convergence

Caldentey (2012) investigated the economic and political development of Chile. The Author described the free-market liberalization of Chile in the 1970 as a main factor driving the growth processes. Despite some descriptive comparison of macroeconomic indicators, no specific convergence-verification methodology was applied. Since the transformation in 1970, the Chilean economy boomed. After 1990 its income convergence experienced a slowdown.

Escobari (2004) verified the convergence hypothesis in case of 19 Latin American countries during the post-war period (1945 to 2000). Two methods were applied: the Bernard and Durlauf (1995) method and unit root tests. The results were mixed, because in case of four countries stochastic convergence was significant at a level of 0.01 and three at 0.05. The beta convergence was analysed separately for regional leaders of economic growth, namely for Argentina, Chile, Mexico, Uruguay and Venezuela.

A qualitative approach of convergence was presented by González, Dabús, and Monterubbianesi (2013). They discussed simple descriptive statistics to investigate growth processes in Latin American countries in the period 1960-2005. There was no strong evidence supporting trends for absolute income convergence for the whole set of analysed countries. Generally, the convergence process was stronger until the middle of the 1970's, but afterwards substantial divergence occurred. There is some evidence in favor of sigma divergence from 1960 until 2005 with some decreases in 1970s and increases especially from 1990s.

Rodríguez-Benavides, López-Herrera and Venegas-Martínez (2014) utilized a framework from Philips and Sul (2007). The main idea was to test the sensitivity of the convergence effect with respect to a filtering procedure performed on analysed series. For the filtered series only Nicaragua and Bolivia were subject to GDP convergence. The Authors also performed tests without filtering the data and identified four convergence groups (categories) among Latin American countries. The strongest trends were reported for Guatemala and Paraguay.

King and Ramlogan-Dobson (2015) revisited the problem of economic convergence of Latin American countries, which this time showed evidence for the convergence hypothesis. The procedure of standard unit-root tests applied in their earlier work (King and Ramlogan-Dobson, 2008) was replaced by a set of Fourier-Type tests. Just like in their initial article, empirical analyses were based on the set of 18 Latin American countries during the period from 1950 to 2009. The application of nonstandard tests resulted in quite positive findings, that all countries except Bolivia showed convergence towards an external benchmark. The evident failure of empirical verification of convergence hypothesis in their previous study, the Authors explained by rather complex dynamics of observed series and nonlinear nature of relationships between analysed economies. King and Ramlogan-Dobson (2016) continued their research, showing rather similar results to those in the previous paper. The Authors showed serious limitations of relative income measurement. Also, they clearly stated that assumptions necessary to apply unit-root tests were not fulfilled in case of Latin America. This time, the Authors worked on a set of 22 Latin American and Caribbean countries, where Argentina was set as a benchmark. A convergence subset of eight countries was confirmed and another one with seven countries was identified.

Testing non-stationarity of income differences in a Markov-Switching environment was subject to analyses by Holmes (2006). In this paper the convergence hypothesis was examined in a set of 8 Latin American countries in the period from 1900 to 2003. Tests were performed on the basis of a version of Dickey and Fuller test, augmented by the assumption of Markov Switching nature of observed processes. For the majority of analysed countries convergence was empirically verified. The reference value, 2% of the speed of convergence rate, may be much too low when modelling the dynamics of observed series using Markov Switching models.

SURE as yet another departure from the standard scheme of convergence analysis

As a conclusion of the previous section one may express the trivial statement that the empirical verification of convergence hypothesis in case of Latin American countries is still an open question, just like in the case of many emerging economies. Attempts presented by Dobson and Ramlogan (2002a, 2002b) clearly showed all drawbacks related to the panel regression techniques when applied to verification of the convergence hypothesis. When analysing a group of countries with certain political, historical or geographical similarities, one may find substantial economic heterogeneity manifested by very vague information contained in cross-sectional observations. Consequently estimates of quantities of interest (like convergence parameter) are often statistically insignificant. It does not preclude analysing economic hypotheses but simply indicates that there is no necessary empirical information to confirm them. A time series approach, based on unit root tests, does not resolve the aforementioned econometric problems. The statistical approach utilising stationary stochastic processes and a random walk hypothesis, relies on an assumption that observables are Gaussian and can be described as linear filters of Gaussian white noise series. These assumptions, while playing a crucial role in the theory, are not met in many empirical cases. Thus, the time series approach is also subject to criticism; see Galvao and Gomes (2007) and King and Ramlogan-Dobson (2015, 2016).

The aim of this paper is not to resolve all problematic issues discussed previously that make empirical verification of the convergence hypothesis such a difficult task. In order to put a small step forward we propose a novel framework for convergence testing which may serve as a substitute for panel regression techniques. Our model is built on the basis of the econometrics of the Seemingly Unrelated Regression Equations (SURE), initially elaborated by Arnold Zellner more than a half century ago; see Zellner (1962). Zellner's methodology departs from the commonly adopted cross sectional regression analysis and enables detailed insight into heterogeneity of relationship between explanatory variables and related variables observed for particular units. Our approach seems a convincing alternative to the panel regression approach where random effects can be estimated, imposing an assumption about the constancy of structural parameters within the group of countries under analysis. Here, thanks to Zellner's contribution, we are allowed to relax the assumption of constancy of parameters, leading to a much more generalised econometric structure.

To start, just like in the paper by Pipień and Roszkowska (2018), we refer to the standard regression form of the conditional convergence equation for a particular country for observed values in time points t=1,…,T:

$$\Delta \ln(y_t) = \alpha_0 + \sum_{i=1}^{m} \alpha_i z_{it} + \beta \ln(y_{t-1}) + \varepsilon_t, \quad (1)$$

where: y_t denotes labour productivity (GDP per employed) in year t (in PPP); z's are sets of additional explanatory variables determining productivity in an equilibrium. Parameter β describes the speed of convergence and, according to theory it is expected to be negative. The set of explanatory variables in (1) conditioning the analysed effect can be determined empirically.

In this paper, following Pipień and Roszkowska (2018), the vector of explanatory variables consists of investment rates, government expenditure in relation to GDP, the inflation rate, and trend as a proxy for institutional or technological changes. Sala-i-Martin (1997) presented a comprehensive study determining empirical importance of factors explaining variability of the per capita output growth rates among countries all over the world. For a particular country, the equation (1) has the following form:

$$\Delta \ln(y_t) = \alpha_0 + \alpha_1 \left(\frac{G_t}{Y_t}\right) + \alpha_2 \pi_t + \alpha_3 \pi_t^2 + \alpha_4 i_t + \alpha_5 t + \beta \ln(y_{t-1}) + \varepsilon_t, \quad (2)$$

where y_t denotes GDP in the country at year t, G_t denotes government consumption expenditure in country in year t, i_t is the investment rate (gross fixed capital formation in relation to GDP), π_t is the inflation rate (percentage change of consumer prices over previous year), and t is the time trend component. The most important interpretable parameter in (2) is the rate of convergence , however, some additional information about the long-term growth rate of labour productivity can be analysed by estimating the nonlinear function of parameters given by

$$g = -\frac{\alpha_5}{\beta} \quad (3);$$

see: Pipień and Roszkowska (2018).

Next, we perform a cross-sectional analysis on the basis of the system of regression equations as an alternative for the very popular strategy utilising the panel regression approach. Supposing we analyse n countries, and for j-th country (j=1,…,n) the convergence regression (2) is considered:

$$\Delta \ln(y_{tj}) = \alpha_{0j} + \alpha_{1j} \left(\frac{G_{tj}}{Y_{tj}}\right) + \alpha_{2j} \pi_{tj} + \alpha_{3j} \pi_{tj}^2 + \alpha_{4j} i_{tj} + \alpha_{5j} t + \beta_j \ln(y_{t-1,j}) + \varepsilon_{tj} \quad (4)$$

The assumption that for each j, the Gaussian error terms ε_{tj} in (4) are uncorrelated, makes the system of equations independent. This case, denoted by M_0, formally refers to the empirical strategy of estimating convergence parameters separately within a particular j-th regression. However, in general, error terms ε_{tj} may exhibit cross correlation, and the system (4) can be treated as a SURE model; see Zellner (1962). We define this case as M_1. Nonzero contemporaneous correlations of error terms in (4) define a more ample stochastic structure particularly suitable for testing formally M_0 as a special case. The standard interpretation of nonzero contemporaneous correlations is also used as indicators describing linkages in the variability of related parameters across countries.

In our notation $\varepsilon_t = (\varepsilon_{t1}, \ldots, \varepsilon_{tm})$ is the row vector of error terms at time t with the covariance matrix Σ. In the case of model M_1, the Σ matrix is symmetric and positive definite with $\frac{n(n+1)}{2}$ free elements σ_{ij}^2, i=1,…, n and j=1,…, n. The variance of the error terms in the i-th country is denoted by $\sigma_{ii}^2 > 0$ and covariance between error terms in the j-th and i-th country stays as σ_{ij}^2. The system of equations (4) can be formulated in the following standard regression form:

$$y^{(j)} = z^{(j)}\alpha^{(j)} + y_{-1}^{(j)}\beta_j + \varepsilon^{(j)}, j=1,\ldots, n$$

where $y_{[t\times 1]}^{(j)} = (y_{1j}, \ldots, y_{Tj})'$, $z_{[T\times 6]}^{(j)} = (z_{1j}{}', \ldots, z_{Tj}{}')'$,

with $z_{tj} = (1, \frac{G_{tj}}{Y_{tj}}, \pi_{tj}, \pi_{tj}^2, i_{tj}, t)$, $y_{[t\times 1]}^{(j)} = y_{-1}^{(j)} = (y_{0j}, \ldots, y_{T-1,j})'$, $\varepsilon^{(j)} = (\varepsilon_{1j}, \ldots, \varepsilon_{Tj})'$,

$$\alpha^{(j)} = (\alpha_{0j}, \alpha_{1j}, \alpha_{2j}, \alpha_{3j}, \alpha_{4j}, \alpha_{5j})'.$$

In the next step, we stack the observations expressing the system of regression equations in the closed form:

$$Y = Z\alpha + Y_{-1}B + \varepsilon \quad (5)$$

where $Y_{[nT\times 1]} = (y^{(1)\prime}, \ldots, y^{(n)\prime})'$, $\varepsilon_{[nT\times 1]} = (\varepsilon^{(1)\prime}, \ldots, \varepsilon^{(n)\prime})'$,

$\alpha_{[n6\times 1]} = (\alpha^{(1)\prime}, \ldots, \alpha^{(n)\prime})'$, $B = (\beta_1, \ldots, \beta_n)'$ and:

$$_{[nT\times n6]}=\begin{bmatrix} Z^{(1)} & 0_{[T\times 6]} & \cdots & 0_{[T\times 6]} \\ 0_{[T\times 6]} & Z^{(2)} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0_{[T\times 6]} \\ 0_{[T\times 6]} & \cdots & 0_{[T\times 6]} & Z^{(n)} \end{bmatrix}, \quad Y_{-1}=\begin{bmatrix} y_{-1}^{(1)} & 0_{[T\times 1]} & \cdots & 0_{[T\times 1]} \\ 0_{[T\times 1]} & y_{-1}^{(2)} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0_{[T\times 1]} \\ 0_{[T\times 1]} & \cdots & 0_{[T\times 1]} & y_{-1}^{(n)} \end{bmatrix}.$$

The system (5) can be written in the following form:

$$Y = X\theta + \varepsilon\,,$$

with matrix $X_{[nT\times 7n]}$ of the form:

$$X=\begin{bmatrix} X^{(1)} & 0_{[T\times 6]} & \cdots & 0_{[T\times 6]} \\ 0_{[T\times 6]} & X^{(2)} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0_{[T\times 6]} \\ 0_{[T\times 6]} & \cdots & 0_{[T\times 6]} & X^{(n)} \end{bmatrix}=\begin{bmatrix} [Z^{(1)}\colon y_{-1}^{(1)}] & 0_{[T\times 7]} & \cdots & 0_{[T\times 7]} \\ 0_{[T\times 7]} & [Z^{(2)}\colon y_{-1}^{(2)}] & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0_{[T\times 7]} \\ 0_{[T\times 7]} & \cdots & 0_{[T\times 7]} & [Z^{(n)}\colon y_{-1}^{(n)}] \end{bmatrix}$$

and $\theta = (\alpha^{(1)'}, \beta_1, \dots, \alpha^{(n)'}, \beta_n)'$.

As the next step, we analyse two nontrivial restrictions of the system (5) allowing either for cross country heterogeneity of $\alpha's$ or $B's$ separately. In the first case, denoted by M_β we allow convergence parameters to vary across countries, however the impact of regressors in (4) is not of country specific nature. Hence in M_β we have:

$$\Delta\ln(y_{tj}) = \alpha_0 + \alpha_1\left(\frac{G_{tj}}{Y_{tj}}\right) + \alpha_2\pi_{tj} + \alpha_3\pi_{tj}^2 + \alpha_4 i_{tj} + \alpha_5 t + \beta_j \ln(y_{t-1,j}) + \varepsilon_{tj} \qquad (6)$$

Formally we can rewrite the system (6) in the following form:

$$Y=\begin{bmatrix} Z^{(1)} \\ \vdots \\ Z^{(n)} \end{bmatrix}\alpha^{\#} + Y_{-1}B + \varepsilon\,,$$

where $\alpha^{\#} = (\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5)'$, while $B = (\beta_1, \dots, \beta_n)'$ just like in (5).

In the second restricted case, denoted by M_α we allow regressors in (4) to have a diverse impact on $\Delta\ln(y_t)$however the convergence parameter is constant. Hence in M_α we have:

$$\Delta\, ln(y_{tj}) = \alpha_{0j} + \alpha_{1j}\left(\frac{G_{tj}}{Y_{tj}}\right) + \alpha_{2j}\pi_{tj} + \alpha_{3j}\pi_{tj}^2 + \alpha_{4j} i_{tj} + \alpha_{5j} t + \beta\, ln(y_{t-1,j}) + \varepsilon_{tj} \qquad (7)$$

Equation (7) yields the following system:

$$Y = Z\alpha + \begin{bmatrix} y_{-1}^{(1)} \\ \vdots \\ y_{-1}^{(n)} \end{bmatrix}\beta + \varepsilon\,,$$

where β is the convergence parameter common to all countries.

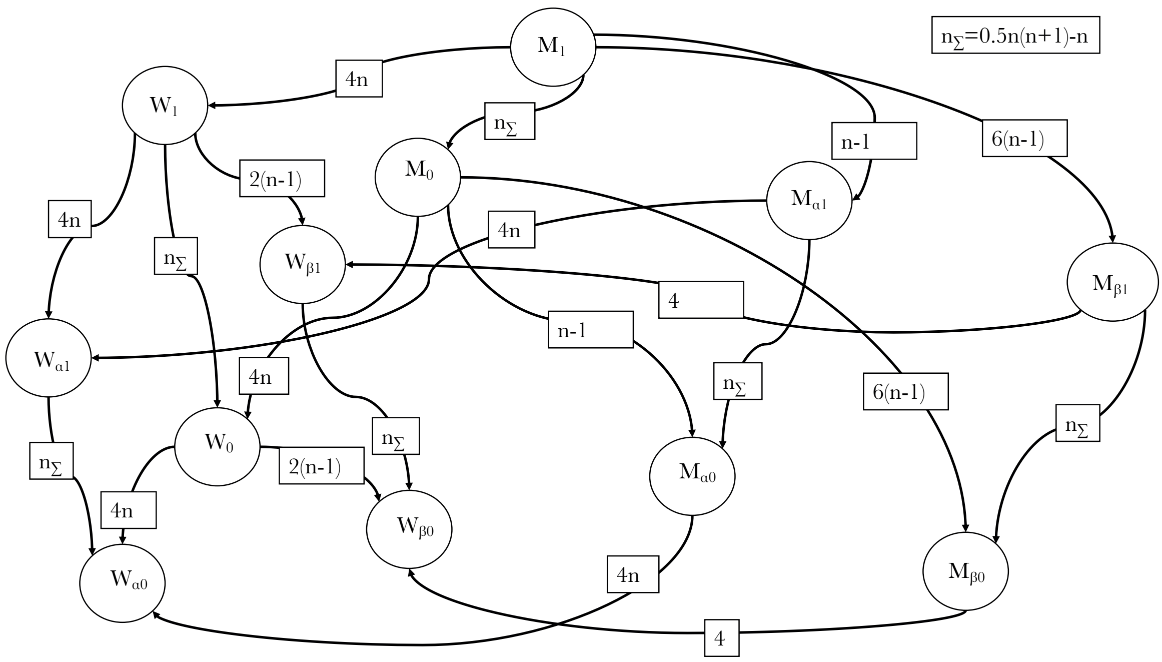
Both restricted cases can be estimated given two stochastic assumptions, resulting in the general model framework with models M_0 and M_1. Consequently models $M_{\beta 0}$ and $M_{\beta 1}$ assume for matrix Σ respectively diagonal form (like in M_0) or unconstrained form (like in M_1).

We also tested whether the set of explanatory variables plays empirically an important role when analysing conditional convergence. To perform this task we consider a model W with zero restrictions imposed on α_i, for i=1,2,3 and 4, leaving the intercept, trend component and convergence part. This leads to the following convergence equation:

$$\Delta \ln(y_{tj}) = \alpha_0 + \alpha_5 t + \beta_j \ln(y_{t-1,j}) + \varepsilon_{tj} \quad (8)$$

Analogously to M_0 and M_1 one may consider W_0 or W_1 depending on the form of matrix Σ (diagonal or unconstrained). Also using the strategy discussed above, it is possible to define some restricted cases $W_{\alpha 1}$ and $W_{\beta 1}$ (i=0,1). Specifications $W_{\alpha 1}$ restrict (8) resulting with existence of a single convergence parameter β, just like in (7). On the other hand, models $M_{\beta 0}$ and $M_{\beta 1}$ enable convergence parameters to vary across countries, however the trend component in (8) is common. Figure 1 shows inclusion relationships between competing models. Axes identify nested specifications, while symbols in rectangles inform about the number of restrictions required to be imposed in order to obtain a less parameterised model. In the empirical part of the paper we discuss statistical relevance of all possible restrictions with the use of the likelihood ratio test.

Figure 1. Graph illustrating inclusion relationship between competing specifications



Note: Axes indicate restrictions possible to impose. Symbols in rectangles denote the number of restrictions required to obtain less parameterised model; n denotes number of equations in (4), while $n_\Sigma = \frac{1}{2}n(n+1) - n$.

Source: own elaboration

Some details related to estimation methods can be found in Olszak and Pipień (2016) and Pipień and Roszkowska (2018). The form of the covariance matrix of ε makes the equation system (5), as well as other analysed model specifications, a generalised linear regression model. Based on Σ, the Aitken Generalised Least Squares estimator of all parameters in the system can be applied according to Zellner (1962).

Empirical analysis

Our dataset consists of annual observations of the GDP per capita growth rate and other macroeconomic indicators as in (4), taken from n=10 Latin American countries: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay and Venezuela. We rely on data covering the period from 1954 to 2014; T=61 observations. The source of the whole dataset is the Penn World Table (2014).

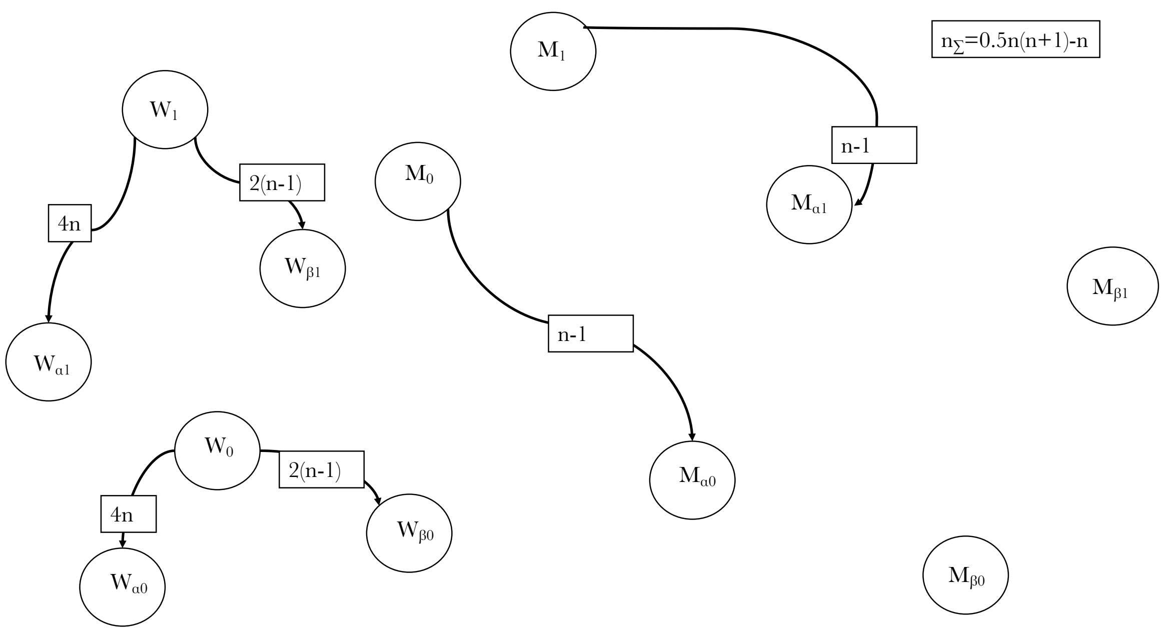
In Table 1 we put logarithms of the likelihood function calculated at ML estimates of parameters. Analysing convergence in case of the framework given by (4) including explanatory variables, unconstrained specification receives the greatest data support. Also model $M_{\alpha 1}$ has relatively high likelihood score, as compared to other specifications being substantially rejected by the data. The diagonal matrix of contemporaneous covariances **Σ** as well as constancy of parameters α are not supported by the data.

Table 1. The value of the Log-Likelihood function calculated at ML estimates for each competing specifications

Full specification (4)		Restricted specification (8)	
Unconstrained Σ in (4)	Diagonal Σ in (4)	Unconstrained Σ in (8)	Diagonal Σ in (8)
$\boldsymbol{M_1}$ **1132.82**	M_0 1057.24	$\boldsymbol{W_1}$ **1065.27**	W_0 951.35
$M_{\beta 1}$ 1067.26	$M_{\beta 0}$ 972.55	$W_{\beta 1}$ 1053.42	$W_{\beta 0}$ 944.38
$M_{\alpha 1}$ 1128.65	$M_{\alpha 0}$ 1050.82	$W_{\alpha 1}$ 1061.74	$W_{\alpha 0}$ 959.38

We tested the statistical significance of restrictions described in the previous section. On Figure 2, the black axes show restricted model specifications that are supported at any reasonable level of significance. Table 2 sums up testing procedure providing *p*-values of the LR test under consideration. There are only six empirically relevant restrictions and among them empirical importance of model $M_{\alpha 1}$ (against unrestricted fully parameterised M_1) receives particular attention. According to (7), in model $M_{\alpha 1}$ we allow regressors to have a country specific impact on variability of the GDP per capita growth rate, imposing constancy of the convergence parameter for the entire group of analysed countries. Consequently our results show that despite empirical supremacy of unrestricted SURE model M_1, that allows for heterogeneity of all parameters including time trend, regressors and convergence, it is possible to estimate parameters informing about the speed of convergence for the whole region, conditional to the existence of country-specific effects determining economic growth.

Figure 2. Graph illustrating empirically important model restrictions



Note: Axes indicate restrictions possible to impose. Symbols in rectangles denote the number of restrictions required to obtain less parameterised model; *n* denotes number of equations in (4), while $n_\Sigma = \frac{1}{2}n(n+1) - n$.

Source: own elaboration

Table 2. Results (as reported by *p*-values) of the LR test of restricted model cases

	M_1	M_0	W_1	$W_{\alpha 1}$	$W_{\beta 1}$	W_0	$W_{\alpha 0}$	$W_{\beta 0}$	$M_{\alpha 0}$	$M_{\beta 0}$	$M_{\alpha 1}$	$M_{\beta 1}$
M_1	-	-	-	-	-	-	-	-	-	-	-	-
M_0	$2.1 \cdot 10^{-13}$	-	-	-	-	-	-	-	-	-	-	-
W_1	$3.0 \cdot 10^{-12}$	-	-	-	-	-	-	-	-	-	-	-
$W_{\alpha 1}$	-	-	**0.63**	-	-	-	-	-	-	-	$4.8 \cdot 10^{-12}$	-
$W_{\beta 1}$	-	-	**0.17**	-	-	-	-	-	-	-	-	$1.5 \cdot 10^{-5}$
W_0	-	$3.1 \cdot 10^{-25}$	$2.9 \cdot 10^{-26}$	-	-	-	-	-	-	-	-	-
$W_{\alpha 0}$	-	-	-	$1.0 \cdot 10^{-25}$	-	**0.92**	-	-	$1.2 \cdot 10^{-23}$	-	-	-
$W_{\beta 0}$	-	-	-	-	$1.5 \cdot 10^{-24}$	**0.60**	-	-	-	$1.7 \cdot 10^{-11}$	-	-
$M_{\alpha 0}$	-	**0.17**	-	-	-	-	-	-	-	-	$4.2 \cdot 10^{-14}$	-
$M_{\beta 0}$	-	$7.8 \cdot 10^{-14}$	-	-	-	-	-	-	-	-	-	$1.2 \cdot 10^{-19}$
$M_{\alpha 1}$	**0.50**	-	-	-	-	-	-	-	-	-	-	-
$M_{\beta 1}$	$2.3 \cdot 10^{-8}$	-	-	-	-	-	-	-	-	-	-	-

Note: Models in a particular row represent null, while models in a particular column represent the alternative hypothesis

In case of the group of models obtained on the basis of restricted framework (8), the data support the hypotheses that model W_1 can be reduced to both $W_{\alpha 1}$ and $W_{\beta 1}$ special cases. The *p*-values for appropriate LR tests are 0.63 and 0.17 respectively; see Table 2. We interpret this result as an argument in favour of importance of the explanatory variables included in (4). If we restrict convergence regression only to the time trend and lagged GDP per capita, leading to (8), the uncertainty about mechanisms determining economic growth are strong enough to make the heterogeneity of convergence processes almost impossible to verify.

In Table 3 we report ML estimates of convergence parameters β as well as estimates of asymptotic standard errors. We confront heterogeneity of convergence effect among countries that is possible to obtain in case of models M_1, $M_{\beta 1}$, W_1 and $W_{\beta 1}$ with restricted cases $M_{\alpha 1}$ and $W_{\alpha 1}$. According to the testing exercise discussed above, the model $M_{\alpha 1}$ represents empirically acceptable restricted case of model M_1. The results generated are burdened with high statistical uncertainty about the heterogeneity of convergence processes among countries. The estimated speed of convergence obtained in case of model M_1 may vary substantially across analysed economies and ranges from 24% attached to Bolivia to 5% that characterises Uruguay. Comparing estimated speed of convergence obtained in case of $M_{\alpha 1}$ and $W_{\alpha 1}$ it is clear that 8%-9% value of speed of convergence seems insensitive with respect to the choice of regressors in (4). Also the speed of convergence that is specific to a particular country seems different when comparing models M_1 and W_1. For example the speed of convergence at level 24% reported above for Bolivia (in model M_1) decreases to 13% when estimating model W_1. Also 5% speed of convergence in Uruguay (in model M_1) lowers to modest 1.6% in case of model W_1.

Another interesting observation refers to models $M_{\beta 1}$ and $W_{\beta 1}$. According to (6) explanatory variables utilised in convergence regression have the same impact on the GDP per capita growth rate in case of all analysed countries. In these models we allow β's to vary across countries only imposing cross country constancy of parameters α. However, point estimates of convergence parameters are very similar across countries. The speed of convergence is approximately at 6.5% rate in case of model $M_{\beta 1}$ and at 5% rate in case $W_{\beta 1}$.

Table 3. ML estimates and asymptotic standard errors of convergence parameter β obtained in all specifications with unconstrained covariance matrix Σ (*i*=1)

	M_1	$M_{\alpha 1}$	$M_{\beta 1}$	W_1	$W_{\alpha 1}$	$W_{\beta 1}$
AR	-0.097**		-0.061***	-0.100***		-0.048***
	0.0471		0.0100	0.0328		0.0098
BO	-0.241***		-0.070***	-0.135***		-0.056***
	0.0669		0.0113	0.0360		0.01107
BR	-0.101*		-0.063***	-0.073*		-0.049***
	0.0503		0.0103	0.0410		0.01001
CL	-0.084**		-0.060***	-0.107**		-0.048***
	0.0365		0.0098	0.0416		0.0096
CO	-0.066**	-0.095***	-0.064***	-0.071**	-0.085***	-0.050***
	0.0286	0.0143	0.0101	0.0278	0.0144	0.0099
EC	-0.083**		-0.065***	-0.085***		-0.051***
	0.0372		0.0105	0.0304		0.0102
PY	-0.174**		-0.067***	-0.108*		-0.054***
	0.0654		0.0109	0.0534		0.0107
PE	-0.127***		-0.065***	-0.067*		-0.052***
	0.0334		0.0105	0.0334		0.0103
UY	-0.050		-0.060***	-0.016		-0.048***
	0.0375		0.0096	0.0385		0.0094
VE	-0.082*		-0.063***	-0.111***		-0.049***
	0.0431		0.0099	0.0400		0.0095

Note: Standard notation for significance of point estimates at 0.01, 0.05 and 0.1 is applied as (***), (**) and (*).

Results of inference about the long term growth rate of labour productivity (LTGLP), according to (3), are presented in Table 4. We report ML estimates and asymptotic standard errors of $-\frac{\alpha_5}{\beta}$ obtained in case of all competing specifications (with unconstrained covariance matrix Σ; *i*=1).

Table 4. ML estimates and asymptotic standard errors of the long-term growth rate of labour productivity ($-\frac{\alpha_5}{\beta}$; see formula (3)) obtained in all specifications with unconstrained covariance matrix Σ (*i*=1)

	M_1	$M_{\alpha 1}$	$M_{\beta 1}$	W_1	$W_{\alpha 1}$	$W_{\beta 1}$
AR	0.0355***	0.0353	0.0313***	0.0397***	0.0404	0.0344***
	0.0062	0.0492	0.0031	0.0046	0.0607	0.0045
BO	0.0275***	0.0337	0.0272***	0.0282***	0.0326	0.0296***
	0.0018	0.0468	0.0027	0.0032	0.0499	0.0038
BR	0.0248***	0.0242	0.0302***	0.0314***	0.0316	0.0338***
	0.0047	0.0416	0.0030	0.0047	0.0556	0.0044
CL	0.0362***	0.0338	0.0315***	0.0279***	0.0295	0.0347***
	0.0110	0.0495	0.0031	0.0049	0.0488	0.0045
CO	0.0180***	0.0192	0.0297***	0.0221***	0.0216	0.0333***
	0.0062	0.0287	0.0029	0.0037	0.0348	0.0043
EC	0.0246***	0.0243	0.0292***	0.0252***	0.0252	0.0325***
	0.0038	0.0334	0.0029	0.0040	0.0382	0.0042
PY	0.0332***	0.0378	0.0283***	0.0306***	0.0319	0.0311***
	0.0042	0.0572	0.0028	0.0040	0.0509	0.0040
PE	0.0231***	0.0238	0.0293***	0.0283***	0.0265	0.0322***
	0.0037	0.0402	0.0029	0.0069	0.0473	0.0042
UY	0.0214**	0.0171	0.0315***	0.0579	0.0215	0.0347***
	0.0097	0.0308	0.0031	0.1083	0.0384	0.0044
VE	0.0126	0.0129	0.0302***	0.0099*	0.0109*	0.0339***
	0.0124	0.0106	0.0030	0.0051	0.0064	0.0044

Note: Standard notation for significance of point estimates at 0.01, 0.05 and 0.1 is applied as (***), (**) and (*).

In spite of relatively strong diversity of the convergence effect among countries and models discussed above, estimated values of the long term growth rate of labour productivity seem very stable and not sensitive with respect to restrictions imposed on M_1. In our approach, all analysed specifications report relatively the same estimates of LTGLP indicating that labour productivity grows at rate 2%-3% for the entire region. However, estimates of asymptotic standard errors differ among models. In case of M_1, $M_{\beta 1}$ and $W_{\beta 1}$ the long term growth rate of labour productivity is estimated with relatively greater precision compared to $M_{\alpha 1}$ and $W_{\alpha 1}$. In the latter specification standard deviations are almost ten times greater than in case of model M_1. Despite the heavy parameterisation required in M_1 to assure heterogeneity effects in convergence equations, the statistical uncertainty attached to inference about LTGLP is much smaller than in case of models resulting with imposing restrictions.

Summary

Using the Zellner (1962) system of Seemingly Unrelated Regression Equations (SURE) we tested the empirical relevance of both the existence of convergence effect and its heterogeneity among selected Latin American countries. Two econometric models as alternative frameworks were used in the analyses. In the first case denoted by M a set of explanatory variables was formulated, namely government expenditure in relation to GDP, inflation rate, investment rate and a time trend. Further, initial GDP level with a beta parameter for convergence rate was considered. In the second model only the time trend component as the explanatory variable and the initial GDP level with the beta parameter were taken into account. This model is denoted by W. In case of both models we analysed certain interpretable restrictions. Firstly, all parameters corresponding to explanatory variables and parameter describing convergence effect were set as variable across countries. This constitutes an unconstrained model specification. Secondly we imposed a constant restriction on the convergence parameter, but parameters describing the impact of the explanatory variables to related variable were allowed to change, based on the country. Thirdly we imposed restrictions on parameters corresponding to the explanatory variables to be constant, leaving variability of the convergence parameter across countries. All models were estimated under two stochastic assumptions, where in the first case unconstrained matrix of contemporaneous correlations of error terms was allowed and in the second case we imposed on a matrix to be diagonal.

In the unconstrained model, allowing for heterogeneity of all parameters, the average estimated convergence rate was the highest, reaching a value of 11.03%. Also in this case the fastest speed of convergence can be attributed to Bolivia, catching up at a pace determined by the estimated value of 24.12%. The lowest speed of convergence (at a pace estimated by 4.95%) was reported in case of Uruguay.

We empirically confirmed the convergence hypothesis in the analysed set of countries. However the most important result relates to the substantial heterogeneity of the speed of convergence. This phenomenon, reported in many papers as the most important drawback of standard econometric approaches can be treated formally in the SURE environment. We believe that our results will help to popularise again the SURE methodology, one of the most interesting generalisations of standard linear regression, proposed many decades ago by Arnold Zellner. SURE models may serve as an empirically relevant and tractable approach diminishing the ubiquitousness of panel regression techniques in cross-sectional analyses generally and in the problem of testing the economic convergence particularly.

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List of abbreviations

GDP Gross Domestic Product

OECD Organisation for Economic Co-operation and Development

SURE Seemingly Unrelated Regression Equations

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