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BAYESIAN MODEL AVERAGING IN MODELLING GDP CONVERGENCE WITH THE USE OF PANEL DATA[1]

1. Introduction

Many papers on income-level or real convergence have emerged in recent years. However, the conclusions obtained by various authors depend on the analyzed sample, model specification, and the estimation method. Regarding this last issue, the set of explanatory variables, treated as growth factors, is extremely important. Inclusion of different sets of explanatory variables in the regression model often yields different, not to say contradictory results. Sala-i-Martin, Doppelhofer, and Miller (SDM hereafter)[2] try to solve this problem using Bayesian averaging of classical estimates (BACE) approach. Instead of using one model, they estimate a large number of equations corresponding to numerous possible sets of explanatory variables chosen

[1] This research project has been financed by the National Bank of Poland within the frame of the competition for research grants scheduled for 2012.

[2] X. Sala-i-Martin, G. Doppelhofer, R. Miller, *Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach*, "American Economic Review" 2004, vol. 94, pp. 813–835.

from an initially selected group of "candidate-variables". The results are then averaged using specified weights.

Another problem in performing growth regressions is the stability of parameters. In most empirical studies it is assumed that the impact of regressors on GDP growth is stable over time. It means that the coefficients on particular variables are calculated as one value for the entire period. Such a specification, however, does not provide the full picture of the factors determining the pace of growth. The assumption of the constancy of parameters does not essentially show the full nature of the process of economic growth.

This study tries to shed some light on these doubts and questions. The aims of this analysis are twofold. The first one is to check whether the pace of convergence of the 27 European Union (EU27) countries was constant over time. Second, this study focuses on the analysis of the time stability of the impact of selected macroeconomic variables on economic growth. As there is a huge number of variables that are widely recognized as growth factors, this study focuses on the subset of them. The analysis covers the 1993–2010 period. Bayesian model averaging (BMA) method is applied to Blundell and Bond's GMM system estimator. Moreover, this approach is extended by allowing for structural breaks of some of the variables to assess the turning points and to show whether the impact of a given variable on the pace of economic growth was constant over time.

The paper is composed of five parts. Chapter 2 which shows the theoretical issues related with β convergence and presents the brief review of the literature. Section 3 presents the general idea of BMA and BACE modeling and describes the convergence model with nonstability. Chapter 4 presents the data used and the results of the analysis. Section 5 shows brief concluding remarks.

2. Theoretical issues and the review of the literature

β convergence exists if the GDP of less developed countries (with lower GDP per capita) grows faster than the GDP of more developed ones. This type of convergence can be analyzed in absolute or conditional terms. Absolute convergence means that less developed countries always reveal higher economic growth while conditional convergence confirms the catching-up process only for those countries that tend to reach the same steady state (which – in general – need not be the same across all economies), however, the catching-up process confirmed by neoclassical models of economic growth is not absolute[3]. That indicates that the convergence explained

[3] R.M. Solow, *A Contribution to the Theory of Economic Growth*, "Quarterly Journal of Economics" 1956, vol. 70, pp. 65–94; N.G. Mankiw, D. Romer, D.N. Weil, *A Contribution to the Empirics of Economic Growth*, "Quarterly Journal of Economics" 1992, vol. 107, pp. 407–437.

by neoclassical models occurs with regard to individual steady states to which the countries are tending. The respective models differ, however, in terms of the value of the β coefficiet, which indicates the rate of the catching-up process, according to the following equation:

$$\frac{\dot{y}}{y} = \beta(\ln y^* - \ln y), \tag{1}$$

where: y – GDP per capita in the period t (dot over a variable stands for its time derivative), y^* – GDP per capita in the steady state. Equation (1) implies that the rate of economic growth depends on the income gap with respect to the steady state. β shows what part of the distance towards the steady state the economy is covered during one period. For example, if β = 0.02, the economy is covering annually 2% of the distance.

In empirical studies, authors estimate β for different countries or regions. When the conditional convergence hypothesis is verified (which usually takes place in the case of heterogeneous samples), the key element is proper choice of explanatory variables for the econometric model. The control variables should explain in the best possible way the differences in steady states across countries.

Regarding to steady state factors, on the one hand one can distinguish 'deep' determinants of economic development that measure the countries' institutional environment (political system, economic freedom, geopolitical location, cultural characteristics etc.)[4]. These influence the "direct" variables determining steady state, which include e.g. investments in capital (physical and human capital), fiscal and monetary policy, the size of public sector (the ratio of government expenditure and tax revenue to GDP), openness, structure of the economy, inputs productivity, private sector development, and the quality of infrastructure.

Most empirical studies are methodologically related to the analyses of Barro et al. or by Mankiw, Romer, and Weil[5]. Barro et al. have been continuously conducting empirical studies on economic growth and convergence for various countries and regions. The authors estimate the following regression equation:

$$(1/T)\ln(y_{it} / y_{i,t-T}) = \alpha_0 + \alpha_1 \ln(y_{i,t-T}) + \sum_{k=1}^{K} \phi_k X_{k,it} + \varepsilon_{it}, \tag{2}$$

where: y_{it} – income *per capita* of region or country i in period t, T – the number of years covered by one observation, $X_{k,it}$ for $k = 1, \ldots, K$ – control variables for region or country i in period t, ε_{it} – a random factor. The left-hand side of (2) represents the

[4] See e.g. *Wzrost gospodarczy w krajach transformacji: konwergencja czy dywergencja?*, part 3, ed. R. Rapacki, PWE, Warszawa 2009.

[5] See e.g. R.J. Barro, *Economic Growth in a Cross Section of Countries*, "Quarterly Journal of Economics" 1991, vol. 106, pp. 407–443; R.J. Barro, X. Sala-i-Martin, *Economic Growth*, The MIT Press, Cambridge–London 2003; N.G. Mankiw, D. Romer, D.N. Weil, op.cit.

rate of economic growth. The first variable on the right-hand side ($\ln y_{i,t-T}$) measures the initial GDP *per capita*, so α_1 is used to draw conclusions about the existence and the rate of β convergence. The catching-up process takes place if α_1 is negative and statistically significantly different from zero. Furtheron, the value of coefficient, that measures the rate of convergence, can be computed and the number of years needed for the countries to reduce by half the income gap towards their individual steady states, so-called half-life[6], can be calculated.

There are many empirical studies on convergence – too many to mention all of them. Since this analysis focuses on the EU countries, especially the Central and Eastern European (CEE) countries, it is worth to cite some studies which deal with transition economies. Sarajevs analyzes the convergence of 11 transition countries during the 1991–1999 period confirming the absolute β convergence[7]. Kaitila tests the absolute β convergence for 7 CEE countries and finds that for the period 1995–2001 the convergence coefficient equals 3.4% but for the years 1994–2001 the results are statistically insignificant[8]. Analysis conducted by Rapacki and Próchniak confirms that 10 CEE countries converged at the rate of 2.6% during 1993–2007[9]. Vojinović, Oplotnik, and Próchniak extended the study for CEE countries introducing further control variables and obtained different results regarding convergence depending on the exact set of explanatory factors used[10]. Wolszczak-Derlacz analyzes convergence of EU–27 countries during 1990–2007 with yet another set of control variables[11]. The implied rate of convergence is 2.2–3.2%. Clearly differeing set of controls affects seriously the conclusions drawn.

There are a few studies that incorporate BMA approach to the analysis of economic growth determinants and convergence, including our own analyses, but they are somewhat different from the approach applied in this study[12]. We did not find any analysis that incorporates BMA referring to Blundell and Bond's GMM system estimator and allowing for structural breaks. Our analysis is probably the first study on the subject.

6 D. Romer, *Advanced Macroeconomics*, McGraw-Hill, New York 1996, pp. 22–23.

7 V. Sarajevs, *Convergence of European Transition Economies and the EU: What Do the Data Show*, BOFIT, Discussion Paper (Helsinki) 2001, no. 13.

8 V. Kaitila, *Convergence of Real GDP Per Capita in the EU15. How Do the Accession Countries Fit In?*, ENEPRI, Working Paper (Brussels) 2004, no. 25.

9 R. Rapacki, M. Próchniak, *Economic Growth Paths in the CEE Countries and in Selected Emerging Economies, 1993–2007*, "Research in Economics and Business: Central and Eastern Europe" 2010, vol. 2, pp. 5–33.

10 B. Vojinović, Ž.J. Oplotnik, M. Próchniak, *EU Enlargement and Real Economic Convergence*, "Post--Communist Economies" 2010, vol. 22, pp. 303–322.

11 J. Wolszczak-Derlacz, *Does Migration Lead to Economic Convergence in an Enlarged European Market?*, "Bank i Kredyt" 2009, vol. 40, pp. 73–90.

12 Those include, among others: X. Sala-i-Martin, G. Doppelhofer, R. Miller, op.cit.; E. Moral-Benito, *Determinants of Economic Growth: A Bayesian Panel-Data Approach*, CEMFI, Working Paper (Madrid) 2010, no. 719; A. Ciccone, M. Jarociński, *Determinants of Economic Growth: Will Data Tell?*, "American Economic Journal: Macroeconomics" 2010, vol. 2, pp. 223–247; M. Próchniak, B. Witkowski, *Konwergencja gospodarcza typu β w świetle bayesowskiego uśredniania oszacowań*, "Bank i Kredyt" 2012 (in print).

3. Bayesian model averaging algorithm and non--stability

BMA approach has gained popularity over the last decade, though has been present in literature in a quite agnostic form for two decades already. Let $X=\{Z_1,Z_2,\ldots,Z_K\}$ be a set of K variables considered as *possible* growth factors. Further let $H=\{V_1,V_2,\ldots,V_C\}$ be a set of C variables that, according to our beliefs, *are* growth factors (including just lagged GDP level in this article). Denoting GDP growth as Y, we can consider 2^K different linear growth regressions such that in each there will be all elements of H and one of the possible subsets of X. In order to estimate $\beta_{X_1},\ldots,\beta_{X_K}$, $\beta_{V_1},\ldots,$ β_{V_M} parameters reflecting the influence of particular X_k's and V_m's on Y without restricting attention to one model with selected elements of X, a kind of BMA can be used. The idea of BACE, which if one of the BMA algorithms used when a linear model is estimated via least squares method, is the following. First, we estimate all the possible 2^K above mentioned models M_1, …, M_J (or, with bigger K, a number of models based on drawn subsets of X, which we also do in this paper). We denote the subset of X used in M_j as X_j and the number of elements in M_j as K_j.

We do not know which of the M_j's is the true one, but some prior probabilities of relevance are assigned to each of them. This is not an obvious step, since there are various possibilities of defining priors. A common option is to assume that the prior probabilities are equal for all the variables in X. Assuming independence of Z_k's and dentotong the number of Z_k's in the true model as $\bar{k}$, prior probability for each Z_k equals $\frac{k}{K}$ and the prior probability for M_j is

$$\mathrm{P}(M_j)=\left(\tfrac{\bar{k}}{K}\right)^{K_j}\left(1-\tfrac{\bar{k}}{K}\right)^{K-K_j}. \tag{3}$$

Let D be the data used. The main point of interest lies in the posterior M_j probabilities, $\mathrm{P}(M_j|D)$, which are prior probabilities "corrected" by to which extent D supports M_j as the true model. Using Bayes rule we get:

$$\mathrm{P}(M_j\,|\,D)=\frac{\mathrm{P}(M_j)\mathrm{P}(D\,|\,M_j)}{\sum_{i=1}^{J}\mathrm{P}(M_i)\mathrm{P}(D\,|\,M_i)}. \tag{4}$$

Let $\mathrm{L}(D,b_j)$ be the likelihood of M_j and θ_j be the vector of parameters of M_j. The probability of D being generated by M_j is:

$$(D\,|\,M_j)=\int \mathrm{L}(D,\theta_j)\mathrm{P}(\theta_j\,|\,M_j)\mathrm{d}\theta_j. \tag{5}$$

This is the point, where different BMA algorithms start differing significantly. Since (5) is computationally problematic, SDM in their BACE algorithm suggest approximating (5) with Schwarz's Bayesian information criterion[13]. Doing that simplifies (4) to:

$$\mathrm{P}(M_j \mid D) = \frac{\mathrm{P}(M_j) n^{-(K_j+C)/2} \mathrm{SSE}_j^{-n/2}}{\sum_{i=1}^{J} \mathrm{P}(M_i) n^{-(K_i+C)/2} \mathrm{SSE}_i^{-n/2}}, \tag{6}$$

where n stands for the number of observations in D, while SSE_j is the sum of squared residuals of M_j. One can now find the probabilities of relevance of particular Z_i's, as well as the estimates of $\beta_{Z_1}, \ldots, \beta_{Z_K}, \beta_{V_1}, \ldots, \beta_{V_C}$ parameters treating (6) as weights. Let $\hat{\beta}_{r,j}$ stand for the estimator of any parameter (whether β_{Z_K} or β_{V_C}) in model M_j, let $\hat{\beta}_r$ be the "final" estimator of parameter r, being the result of the total BMA process. Let us denote their variances as $\mathrm{Var}(\hat{\beta}_{r,j})$ and $\mathrm{Var}(\hat{\beta}_r)$ respectively. Finally, let $\mathrm{P}(Z_k|D)$ be the posterior probability of relevance of a given Z_k. Then

$$\hat{\beta}_r = \sum_{j=1}^{J} \mathrm{P}(M_j \mid D) \hat{\beta}_{r,j} \tag{7}$$

$$\mathrm{Var}(\hat{\beta}_r) = \sum_{j=1}^{J} \mathrm{P}(M_j \mid D) \cdot \mathrm{Var}(\hat{\beta}_{r,j}) + \sum_{j=1}^{J} \mathrm{P}(M \mid D) \cdot (\hat{\beta}_{r,j} - \hat{\beta}_r) \tag{8}$$

and

$$\mathrm{P}(Z_k \mid D) = \sum_{j: Z_k \in X_j} \mathrm{P}(M_j \mid D). \tag{9}$$

However, if the model is estimated with a method different than the least squares, (6) will look differently. Suppose now, that the growth regression of interest is estimated on the basis of panel data covering a set of countries observed over subsequent periods (years). The problem arises due to the dynamics of the model. A typically adopted approach is to use one of the GMM-type estimators with Blundell and Bond's difference estimator being the natural choice[14]. An important feature is that, contrary to BACE, when instrumental variables estimators are used, we are able to relax the assumptions of exogeneity, treating selected independent variables as endogenous.

BMA with the use of Blundell and Bond's estimator requires changing the way (6) is computed. Let $\mathrm{Q}(\theta_j)$ be the GMM loss function that is minimized while estimating M_j. Kim shows, that[15]

$$\ln \mathrm{P}(D \mid M_j) = -0.5n\mathrm{Q}(\hat{\theta}_j) - 0.5K'_j \ln n \tag{10}$$

with K'_j standing for the (total) number of parameters of M_j and $\mathrm{Q}(\hat{\theta}_j)$ standing for the minimized value of $\mathrm{Q}(\theta_j)$ is the limited information likelihood analog to

13 G. Schwarz, *Estimating the Dimensions of a Model*, "Annals of Statistics" 1978, vol. 6, pp. 461–464.

14 R. Blundell, S. Bond, *Initial Conditions and Moment Restrictions in Dynamic Panel Data Models*, "Journal of Econometrics" 1998, vol. 87, pp. 115–143.

15 J.-Y. Kim, *Limited Information Likelihood and Bayesian Analysis*, "Journal of Econometrics" 2002, vol. 107, pp. 175–193.

Schwarz's BIC. That, after proper substition, allows to write the posterior probability of M_j, the analog of (6) as:

$$\mathrm{P}(M_j \mid D) = \frac{\mathrm{P}(M_j) n^{-K'_j/2} \exp[-0.5n\mathrm{Q}(\hat{\theta}_j)]}{\sum_{i=1}^{J} \mathrm{P}(M_i) n^{-K'_i/2} \exp[-0.5n\mathrm{Q}(\hat{\theta}_i)]}, \tag{11}$$

whereas formulas (7)–(9) remain unchanged.

A problem related with many economic models is the possible lack of stability. For instance, if we were to consider a group of CEE countries in the period that covers late 80's or early 90's of the twentieth century[16], it would be rational to allow for structural break somewhere around the 1990. Certainly in case of some of the independent variables assuming stability of the way they influence ln *GDP* is rational, still for some of them – it is not sensible anymore.

Crespo Cuaresma and Doppelhofer[17] consider the case of differing regimes overtime. In their model they introduce a set of variables that are potentially causing "threshold nonlinearity". The name "nonlinearity" comes from the fact that the variables that change the regime overtime are introduced by means of interaction terms, which, being a product of variables, can indeed be viewed as nonlinear. In our model we introduce the nonstability in a manner that is partly similar. We divide the entire period covered by the considered panel into a few subperiods and assume that the way all independent variables affect the dependent variable is constant for a given subperiod, but might differ in different subperiods for some preselected variables. Let us define "regime" variables: $R_1, R_2, \ldots, R_U$ with U standing for the number of subperiods the series have been divided into. Each $R_{u,t}$, standing for the value of "R" variable for u-th subperiod ($u = 1, \ldots, U$), takes on a value of 1 for such observation on the i-th object (country) in period t, that t is covered by the u-th subperiod and 0 otherwise. Let V_c be a variable whose influence on the dependent variable can be different in particular subperiods. In order to test for the stability of this influence, we include in H a set of independent variables that are products of V_c and particular R_u's, $u = 1, \ldots, U$, that is: $\{S_{V_c,2} = \{V_c, V_c R_1, V_c, R_2\}$. In order to check for stability of the influence of the considered V_c, we need to check for significance of differences in the parameters on such set of products, that can be viewed as interaction terms of V_c and R_u's. Another possibility is to introduce the V_c and the products of V_c with any U–1 of the UR_u's, that is, for instance, $S_{V_c,2} = \{V_c, V_c R_1, V_c R_2, \ldots, V_c R_{U-1}\}$. In this case checking for the discussed stability would consist in checking for significance of the

[16] Like, for example, M. Próchniak, B. Witkowski, *Real β Convergence of Transition Countries – Robust Approach*, "Eastern European Economics" 2012 (in print).

[17] J. Crespo-Cuaresma, G. Doppelhofer, *Nonlinearities in Cross-Country Growth Regressions: A Bayesian Averaging of Thresholds (BAT) Approach*, "Journal of Macroeconomics" 2007, vol. 29, pp. 541–554.

$V_c R_1, V_c R_2, \ldots, V_c R_{U-1}$ set itself. The latter approach is used for lagged GDP, whereas the first method is applied for all the other variables from the H set[18].

4. Data and empirical results

This analysis models economic growth measured by GDP per capita at purchasing power parity (PPP) in constant prices, calculated as the difference between the log GDP per capita levels in the two consecutive years. The variable measuring initial income level is the log GDP per capita at PPP in the preceding year, the only variable that according to our belief constitutes the H set. 22 growth factors, listed in Table 1, are tested reflecting the differences in steady states in the X set. The selection of control variables is in line with empirical studies: the growth factors used are mostly included in the studies on convergence. Our study is based on a partly balanced panel. This means that, if a given observation is included, there are no missing values of any of the explanatory variables.

The control factors are divided into three groups: endogenous, predetermined and exogenous variables. The division is made on the basis of the economic theory but, to some extent, it reflects our own opinions and there is room for arbitrary choice. All the variables associated with monetary and fiscal policies are treated as endogenous. This reflects the fact that they are likely to be mutually correlated with GDP. Moreover, some other variables are classified as endogenous: those which are related with components of aggregate demand; human capital variables; and the value added in services. Predetermined variables include qualitative indices referring to deep growth determinants: indices of economic freedom and democracy. The main idea of classifying index of economic freedom as the predetermined variable is the fact that it is based on a variety of category indices and many of them represent the country's macroeconomic performance observed in the earlier years. The group of exogenous variables includes all the remaining variables, mainly related with population and health.

Since this study focuses on the time stability of parameters, many variables are included into the model with interactions. Table 1 lists the variables for which the time stability of parameters is verified.

[18] For the variables from H both methods are equivalent, still they are not for the elements of X since not all the interactions appear in a given M_j at once and the first approach should be applied.

Table 1. The set of explanatory variables

Name	Type*	Description	Source
lngdp0	EI	Lagged log GDP per capita at PPP (2005 constant prices)	PWT 7.0
int_rate	EI	Interest rate (%)	EC, WDI
Inf	EI	Inflation (annual %)	IMF, WDI
Cred	EI	Annual change (in % points) of the domestic credit provided by banking sector in % of GDP	WDI
money_gr	EI	Money growth (in constant prices)	EC, WDI
Monet	EI	Monetization ratio (broad money/GDP)	EC, WDI
Inv	EI	Gross fixed capital formation (% of GDP)	WDI
gov_cons	EI	General government consumption expenditure (% of GDP)	WDI
Open	EI	Openness ((exports + imports) / GDP)	WDI
Fdi	E	Net FDI inflow (% of GDP)	WDI
school_tot	E	Average years of total schooling (population ages 15+)	BL
school_ter	E	Percentage of population (ages 15+) with completed tertiary education	BL
edu_exp	E	Education expenditure (% of GNI)	WDI
Serv	E	Services value added (% of GDP)	WDI
Econ_free	P	Index of economic freedom (0–10 scale; 10 = the best outcome)	FI
Dem	P	Democracy index: average of civil liberties and political rights (0–1 scale; 1 = the best outcome)	FH
Life	X	Log of life expectancy at birth (years)	WDI
Fert	X	Log of fertility rate (births per woman)	WDI
pop_15_64	X	Population ages 15–64 (% of total)	WDI
pop_tot	X	Log of population, total	WDI
pop_gr	X	Population growth (annual %)	WDI
pop_den	X	Log of population density (people per sq. km of land area)	WDI
Tel	X	Telephone lines (per 100 people)	WDI

*E = endogeneous; X = exogeneous; P = predetermined; I = interaction terms introduced

Source: BL – R.J. Barro, J.-W. Lee, Education Statistics Database, 2012 (http://databank.worldbank.org/); EC – Eurostat, Database, 2012 (http://epp.eurostat.ec.europa.eu); FH – Freedom House, Freedom in the World Database, 2012 (http://www.freedomhouse.org/); FI – Fraser Institute, Economic Freedom of the World Database, 2012 (http://www.freetheworld.com/); IMF – IMF, World Economic Outlook Database, September 2011 (http://www.imf.org/external/pubs/ft/weo/2011/02/weodata/index.aspx); PWT 7.0 – A. Heston, R. Summers, B. Aten, Penn World Table Version 7.0, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, March 2011 (http://pwt.econ.upenn.edu/); WDI – World Bank, World Development Indicators Database, 2012 (http://databank.worldbank.org/).

One can be mostly suspicious about the non-stability of influence of monetary policy variables and those are first of all interacted in order to take account of a possible structural break. The existence of two structural breaks are expected: in 1998 and 2004. The first turning point is related with two things: (a) half-life between the end of transformation recession in most of the CEE countries and the year of the first EU enlargement, (b) the Russian crisis. The choice of the second structural break is due to the time of the first EU enlargement. As a result, the time intervals between turning points are the following: 1993–1998, 1999–2004, and 2005–2010.

One issue is the assumption on $\bar{k}$, the number of variables from the X set in the 'true' model. The results described in this paper are for $\bar{k} \approx 25\%$ of total K, which equals 12 (yet notice, that it stands for 12 including the interaction variables), however, as a robustness check parallel analysis for different $\bar{k}$'s was carried out and bringing no notable differences in the conclusions, thus only the results for the above mentioned $\bar{k}$ are described.

The results of analysis are given in Tables 2 and 3.

The reference period for the lagged GDP variable is the 2005–2010. In those years, the estimated coefficient standing by lagged GDP in the typical convergence model equals about: 0.94869–1 = –0.051303. The pseudo *t* statistics amounts to 155.53 meaning that, given reasonable significance levels, the coefficient is significantly different from zero. These results confirm the existence of β-convergence of the EU27 countries during 2005–2010. Of course, it is conditional on the growth factors included in the analysis. The coefficient on initial income allows us to calculate the β-convergence parameter, which, for the years 2005–2010, equals 5.27%.

Table 2. Estimation results

Regressor	Period / subperiod	Estimate	Std deviaton	Pseudo t
lngdp0 (*)	2005–2010 (**)	–0.05130300	0.00609974	155.53
	diff. between 93–98 and 05–10	0.00080219	0.00058218	1.38
	Diff. between 99–04 and 05–10	0.00258925	0.00039941	6.48
int_rate	1993–1998	–0.00000009	0.00000001	–5.96
	1999–2004	–0.00002427	0.00001932	–1.26
	2005–2010	0.00007299	0.00004210	1.73
inf	1993–1998	–0.00000003	0.00000001	–5.47
	1999–2004	–0.00000024	0.00000017	–1.43
	2005–2010	0.00000001	0.00000001	8.78

cred	1993–1998	0.00003754	0.00000950	3.95
	1999–2004	0.00000542	0.00000673	0.80
	2005–2010	–0.00000003	0.00000001	–3.84
money_gr	1993–1998	0.00072031	0.00011261	6.40
	1999–2004	0.00000103	0.00000141	0.73
	2005–2010	0.00322305	0.00025384	12.70
monet	1993–1998	0.00000050	0.00000029	1.70
	1999–2004	–0.00000023	0.00000015	–1.51
	2005–2010	0.00000016	0.00000005	3.01
inv	1993–1998	0.00004685	0.00001892	2.48
	1999–2004	0.00000180	0.00000104	1.73
	2005–2010	–0.00000001	0.00000001	–4.67
gov_cons	1993–1998	0.00000149	0.00000301	0.50
	1999–2004	–0.00000314	0.00000258	–1.21
	2005–2010	–0.00000001	0.00000001	–6.24
open	1993–1998	0.00002990	0.00001677	1.78
	1999–2004	–0.00000001	0.00000001	–2.08
	2005–2010	0.00002058	0.00000294	7.01
fdi	The whole period 1993–2010	0.00000001	0.00000001	4.50
school_tot	The whole period 1993–2010	0.00000001	0.00000001	3.48
school_ter	The whole period 1993–2010	–0.00000001	0.00000001	–2.86
edu_exp	The whole period 1993–2010	0.00000049	0.00000024	2.06
serv	The whole period 1993–2010	–0.00000001	0.00000001	–1.53
econ_free	The whole period 1993–2010	0.00000001	0.00000001	7.82
dem	The whole period 1993–2010	–0.00000001	0.00000001	–0.20
life	The whole period 1993–2010	–0.00051825	0.00285562	–0.18
fert	The whole period 1993–2010	–0.00189187	0.00057620	–3.28
pop_15_64	The whole period 1993–2010	0.00023486	0.00019188	1.22
pop_tot	The whole period 1993–2010	–0.00216847	0.00054220	–4.00
pop_gr	The whole period 1993–2010	–0.00012959	0.00029212	–0.44
pop_den	The whole period 1993–2010	–0.00025675	0.00011220	–2.29
tel	The whole period 1993–2010	0.00001986	0.00000518	3.84

Source: own calculations; (*) Functional form of the *estimated* equation requires estimating parameter on lagged GDP incremented by 1, instead of the parameter itself. The estimate of the (**) parameter given in the table is already transformed (1 is substracted from the obtained estimate), however standard deviation refers to “parameter on GDP”+1, thus the value of pseudo-*t* statistic seems not to match the estimate and the standard deviation, but it is calculated properly as the respective ratio from the untransformed model.

Table 3. The results of β convergence

Subperiod	The estimated coefficient on initial income in the untransformed convergence model[a]	The estimated coefficient β	Half-life
1993–1998	–0.050501	5.18%	13.4
1999–2004	–0.048714	4.99%	13.9
2005–2010	–0.051303	5.27%	13.2

[a] The untransformed convergence model assumes that the GDP per capita growth rate is the explained variable.

Source: own calculations.

Comparing these results with the results for earlier subperiods, the coefficient standing by initial income in the typical convergence model for the years 1993–1998 equals: 0.948697 + 0.000802 – 1 = –0.050501, which yields the convergence parameter β = 5.18%. In the years 1993–1998 the convergence process occurred slower than in the years 2005–2010, still pseudo *t* statistics for the lagged GDP in interaction with the first subperiod equals 1.38, which certainly suggests no statistically significant difference between the rate of convergence in the two discussed subperiods. Similarly, the coefficient on initial income in the standard convergence regression for the 1999–2004 subperiod equals –0.048714. It is negative and in absolute terms lower than those for the first and the third subperiods. This indicates a slower pace of convergence during 1999–2004, which is statistically significantly different from the 2005–2010 period. Hence, the conclusion is that during 1999–2004 the β convergence process was slower than in the years 1993–1998 and 2005–2010. The value of the estimated parameter β for the years 1999–2004 equals 4.99%. This estimate is less than 5.18% (for the 1993–1998 period) and less than 5.27% (for 2005–2010), indicating slower β-convergence process. That stands for the number of years the countries need to reduce by half their distance towards the steady state (assuming that steady--states differ only in terms of the control variables included in our model) equal 13.4 in 1993–1998, 13.9 in 1999–2004 and 13.2 in 2005–2010. The conditional β convergence coefficients are relatively high indicating quite rapid achievement of the individual steady states. It means that there are huge differences in marginal products of the inputs in the countries under study. The countries that are poorer record much higher factor productivity and achieve more rapid growth (in conditional terms). However, this also means that gains from being poorer may be exhausted and increasing GDP due to the pure convergence process is limited.

Unlike the initial GDP, whose impact on economic growth was rather stable during the analyzed period, in case of the endogenous variables for which structural breaks are allowed, the impact on the rate of growth varied over time. The interest rate is one of the most important variables determined by the central bank. In the first two subperiods, a negative relationship between interest rate and economic growth was observed but in the years 2005–2010 the coefficient on the interest rate was positive. The positive relationship between interest rate and economic growth may be related with the global economic and financial crisis and very disturbing situation observed in the analyzed countries in the last years. Central banks were decreasing interest rates to boost the economy but these actions did not succeed the growth did not accelerate.

The results for inflation are similar to those for interest rate. Our results do not unambiguously confirm a negative impact of inflation on economic growth in the case of EU27 countries. In most years this impact was negative but the results for 2005–2010 indicate a clear-cut positive relationship between inflation and economic growth. Many of the CEE countries in the 1990s, i.e. just after the transformation recession, noted high inflation rates. Such a high inflation is obviously an obstacle in achieving rapid economic growth. That might be the cause for a significant negative relationship between inflation and economic growth for those years. During 2005–2010, however, inflation rates among the EU members were low (two-digit levels occurred extremely rarely while some countries suffered deflation). In such circumstances, low inflation (or even deflation) need not be a factor conducive to rapid economic growth and that is why a positive sign of the parameter was obtained. This outcome is of course related with the global crisis which had demand-side origins and was accompanied by low inflation.

The results for the annual change of the domestic credit variable are quite interesting. Those clearly show how dangerous the excessive lending in the last years was. During 1993–1998, far before the global crisis when public indebtedness was not extremely high, the estimated coefficient on this variable was positive. This relationship is in line with the theoretical structural model suggesting that financial sector development is conducive to economic growth. But during 2005–2010, i.e. in the period that includes global crisis, the estimated relationship between credit growth and economic growth turned out to be negative. This outcome is an evident proof that credit growth may be sometimes counterproductive. The good example are the Baltic states whose GDP dynamics was mainly based on credit growth and partly because of this fact they suffered the biggest recession in 2009.

The study does not indicate a clear-cut positive impact of investment (saving) on economic growth. During 2005–2010, a negative impact was found. This result emphasizes the need for the revision of some government programs promoting saving.

The outcomes for government consumption show some counterproductive effects of government expenditure policy. During 1993–1998, the corresponding estimated coefficient was positive, yet insignificant and it remained insignificant in the next subperiod. However, in the years 2005–2010, the parameter is found to be negative and statistically different from zero. These suggest that government consumption became more and more unproductive in the last two decades.

Finally, our analysis encompasses a number of other economic growth determinants which are included without interactions. The most significant coefficient belongs to the index of economic freedom. Since economic freedom is a proxy for the country's institutional environment, our research confirms an important role of some types of institutions in stimulating economic growth. However, another institutional variable: the democracy index is insignificant which may be caused by a possible nonlinear relationship with economic growth. Our analysis suggests an important role of FDI in stimulating growth. Regarding human capital, the results are quite in line with expectations but not all the human capital measures turned out to reveal a positive impact on GDP dynamics. Our study reveals that demography has an impact on economic growth: generally, higher economic growth in per capita terms was observed in the countries that are less populated. Moreover, well-developed infrastructure, as measured by the number of telephone lines, was also conducive to rapid output growth.

5. Concluding remarks

The analysis based on panel data has some weaknesses mainly due to the fact that only short-term relationships are examined. Meanwhile, the process of economic growth has also the long-run perspective. Hence, it is worth to perform a similar analysis based on cross-sectional data, including subperiod-averaged figures. This could be a robustness check to our results and such an analysis will be conducted by us in the future. This will give a broader view on the nature of economic growth in the EU countries.

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Summary

Bayesian model averaging in modelling GDP convergence with the use of panel data

In this paper, β convergence analysis for the 27 EU member countries and the 1993–2010 period is conducted. The analysis uses an Bayesian model averaging (BMA) approach applied to Blundell and Bond's GMM system estimator with the existence of structural breaks. In order to account for the differences in the steady--states of the countries, 22 variables are tested as potential economic growth determinants. The structural breaks are expected to be in 1998 and 2004. The main finding is that the EU27 countries converged at the rate of about 5% per annum which is an enormous difference as compared with the widely cited 2% speed of convergence and the mechanism of conditional convergence was rather constant over time yet the influence of particular growth factors on GDP proved not to be stable anymore.

Keywords: Convergence, economic growth, growth factors, bayesian averaging
JEL classification: C11, C23, O40, O47

Autorzy oświadczają, że ich udział w przygotowaniu artykułu był równy.