Characteristics of the Global Innovation Process Based on Short Time Series Analysis

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Abstract: The study was aimed at verifying the existence of a global innovation process by applying Latent Growth Curve Modelling to a short time series of key field indicators. Setting a matrix of time series in the form of a structural model enabled testing functional forms of the processes' dynamics and verifying its dependence on initial levels of the analysed measures. The study unveiled a growth tendency of innovation indicators, pointing to varying functional forms of change, and relations with the initial level of the process. The method also underlined a lack of homogeneity in measurement techniques for innovation statistics.

Keywords: Latent Growth Curve Model, global innovation process, innovation strategy.

1. Introduction

Strategic goals set by European countries and other world economies within their innovation policies point to the existence of a global innovation process [4-6]. It is assumed that this technological progress will be observed in key measures of research and development (R&D) indicators used for monitoring the effectiveness of dedicated policies. The aim of this study is to verify the existence of a common, transnational process of innovation growth, reflecting global activity of countries in raising innovativeness and to unveil characteristics of this process, using a relatively short time series.

The formulated research hypothesis assumes that regularities observable at country level can be considered a common process which can be modelled with formal methods. If this hypothesis holds, this process should intensify in time in all of the analysed economies. The changes that appear globally should be observable in the growth tendency of basic innovation indicators. Moreover, it is assumed that the initial level of a country's innovativeness influences the pace of growth of that process.

Verifying the existence of a common process can be traditionally formulated as a problem of comparison of multivariate means using Multivariate Analysis of Variance [7]. Such an approach, however, focuses on estimating a mean level of change and assigns variance of an individual country's trajectory to residual variation, unexplained by the model. Nonetheless, if we consider the process of innovativeness to be a two level structure, then the regularities observed for each country are classified as regularities of the first level, and those observed among different countries are categorized as regularities of the second level. Therefore, a set of panel data on innovation process dynamics can be treated as a hierarchical structure, where time series and individual observations comprise different levels of analysis. The first level would require analysing individual trajectories of change by studying time series for each country, whereas the second level analysis will focus on a common distribution of trajectories of change for a cohort of countries. Such an approach was verified in this study by the use of Latent Growth Curve Models (LGCM) in structured equation modelling.

LGCM models have been widely applied in biometric and psychometric literature [2]. Applications in socio-economic disciplines are sparse [1, 3, 8, 11], no examples of macro innovation data analysis were found by the authors. Thus the presented approach is new.

The article is organized as follows: section 2 introduces the model, section 3 illustrates the data used for the purpose of the analysis, section 4 presents empirical results and section 5 concludes.

2. Latent growth curve model as a structural model approach

LGCM modelling permits the examination of intraindividual (within-classes) change over time as well as interindividual (between-classes) variability in intraindividual changes. If the moments of observation do not differ in time, the LCGM model can be incorporated into the structural equation modelling framework [9-10, 12]. Such a model is defined by a vector of means μ_y and a covariance matrix Σ of observable variables:

$$\mu_y = \tau + \Lambda\alpha_\eta \tag{1}$$

$$\Sigma = \Lambda\Psi\Lambda + \Theta \,, \tag{2}$$

where τ and α_η are vectors of intercept of observable variables and individual parameters respectively, Λ is a fixed matrix containing a column of ones and columns of constant time values which represent various functional forms of change in time, Ψ and Θ are covariance matrices of regression residuals and measurement error respectively, and $\Sigma = YY^T$, where Y is a matrix of observations. The matrix Σ informs on the level of covariance between the initial level and the pace of change in time ($\psi_{\alpha\beta}$) as well as on inner differentiation of the initial level (ψ^2_{α}) and the pace of change (ψ^2_{β}). As the covariance matrix Θ informs on the dispersion of the measurement error, additional assumptions concerning the structure of this matrix allow to model and test various hypotheses concerning this error.

Setting a matrix of time series in the form of a structural model enables testing various characteristics of the analysed process. Not only varied functional forms of the process but also relations between a model's parameters may be assumed (all additive functions can be considered), which corresponds to a two-stage model with interactions. The effect of interactions is reflected in the dependency between the initial level of the process and its pace of change in time, allowing to seek for the source of differentiation of the analysed measure in its initial level.

3. Empirical grounds for research

This study is based on macro level data collected by Eurostat. Having in mind that resources allocated to a country's R&D efforts are measured using two indicators: R&D expenditure and personnel, frequently referenced in strategic documents on innovation growth [4-6], the following indicators were selected to describe this process:

- Gross domestic expenditure on R&D (GERD) as a percentage of Gross Domestic Product (GDP) – data collected for 31 countries for the period between 2003 and 2010.
- Business expenditure on R&D (BERD) as a percentage of GDP – data collected for 28 countries for the period between 2005 and 2010.
- Share of the number of researchers (in full time equivalents) employed in the business sector (FTERES)[1] – data collected for 28 countries for the period between 2005 and 2010.

4. Estimation of functional forms of the innovation process

Model estimation was performed using the Maximum Likelihood Method in a two-step process. First, four measurement models of time change were estimated: a no-growth model, a linear model, a quadratic[2] model and a logarithmic model. For each

[1] The indicators of BERD and FTERES measures have been logarithmized in order to meet the assumption of normality (verified by the value of skewedness statistics).
[2] In order to assure independence of the significance tests of linear and quadratic components, orthogonal polynomials were used to describe the quadratic time trend model.

process, the best-fitting functional form was selected according to the value of $\frac{\chi^2}{df}$ statistics[3] (see table 1). High values of the test statistics, exceeding the critical level of 5, for all no-growth models have led to dropping the assumptions made for the constant trend function. Thus, the analyzed processes are characterized by change in time. As a result, the process of GERD intensity in GDP was best described by a quadratic model, the intensity of BERD expenditures in GDP by a linear change in time, while the best-fitting model for the share of researchers (FTERES) in business sector was a logarithmic trend.

Table 1. Values of $\frac{\chi^2}{df}$ statistics for the estimated functional forms in time

Indicator:	Value of $\frac{\chi^2}{df}$ statistics for a selected functional form in time			
	Constant	Linear	Quadratic	Logarithmic
GERD intensity in GDP	8,47	3,4	2,96	4,94
FTRES intensity	7,3	13,42	not significant	4,09
BERD intensity in GDP	6,42	2,3	not significant	2,56

Source: own elaboration based on SPSS AMOS 21.0.

The significance of the estimated functional forms indicates that trajectories of change of the analysed processes for the selected group of countries can be described as a global process. This result indicates the existence of a common science and innovation strategy reflected in the analysed measures, and thereby confirms the main research hypothesis formulated in this article.

5. Structural models of time change of the innovation process

In the second step of the analysis, structural models were estimated verifying the dependencies between empirical growth records and measurement errors[4]. In the described models, autocorrelation between the observations distant further than two time periods was assumed not to occur.

[3] The usability of the χ^2 test is low as the value of test statistics is dependent on the number of variables. The statistics $\frac{\chi^2}{df}$ lacks this drawback. The test statistics should not exceed the value of 5 for a well fitting model.

[4] Flexibility in handling structured errors is allowed as the assumption of independent and homoscedastic errors are not realistic for the analysed data. While analysing panel data such correlations between measurement errors are common due to the use of the same measure in the subsequent years. Therefore, the mentioned assumptions can be relaxed allowing for autocorrelation and heteroscedasticity.

5.1. Structural model of the dynamics of GERD intensity in GDP

Table 2 presents estimation results of a structural model of GERD intensity in GDP with a quadratic trend. Significant estimate of slope mean $\mu_\alpha = 0{,}011$ points to a quadratic growth tendency of the variable in time, but no individual deviation for this parameter was determined ($\sigma_\alpha^2 = 0$). Significant deviation, however, was observed for the average linear growth parameter $\widehat{\mu}_\gamma = 0{,}813$ and initial level mean $\widehat{\mu}_g = 0{,}104$. Moreover, estimates of measurement errors were statistically significant, what was not observed for the error variances.

This results implies that in the selected group of countries the average initial level of GERD intensity in 2004 comprised 0,1% of GDP and increased according to a quadratic trend with the slope parameter of 0,01%. As this index describes all financing R&D efforts of a country, the obtained quadratic change suggests an accelerating tendency of countries to finance research and innovation, underlying its growing significance for the economy. It proves a consistent pursuit of the analyzed countries to reach the threshold of GERD expenditures set at the level of 3% of GPD in the strategic documents for the analyzed time period [4-5].

Table 2. Structural model parameters' statistics of GERD intensity in GDP

Model parameters and measurement errors	Parameter estimation statistics				Variance of parameters' estimation statistics			
	Estimate	Standard error	Estimate/ standard error	p-value	Estimate	Standard error	Estimate/ standard error	p-value
$\widehat{\mu}_\alpha$	0,011	0,004	2,602	0,009	0	0,006	-0,056	0,955
$\widehat{\mu}_\gamma$	0,813	0,21	3,871	***	0,784	0,202	3,885	***
$\widehat{\mu}_g$	0,104	0,028	3,693	***	0,116	0,031	3,705	***
e_1	0,006	0,003	2,191	0,028	0,007	0,008	0,939	0,347
e_2	0,002	0,001	1,914	0,056	0,004	0,002	1,717	0,086
e_3	0,001	0	1,964	0,05	0,003	0,001	1,778	0,075
e_4	0,003	0,001	3,067	0,002	0,005	0,002	3,197	0,001
e_5	0,003	0,001	2,937	0,003	0,001	0,001	0,6	0,548
e_6	0,004	0,001	2,892	0,004	0,003	0,003	1,345	0,179
e_7	0,007	0,003	2,627	0,009	0,021	0,005	4,204	***
e_8	0,012	0,005	2,267	0,023	0,023	0,01	2,325	0,02

The symbol "***" means the p-value lower than 0,001.
Source: own elaboration based on SPSS AMOS 21.0.

Moreover, significant correlation between the initial mean level and quadratic change in time was detected, implying a positive dependence (see table 3).The association was not observed for the linear parameter. This result suggests an existing reliance for the pace of this global process, but the relation is not existent for the parameter stabilizing growth in time. According to the model, in the analysed time period the growth is faster for countries which are already considered innovative.

Table 3. Dependencies between model parameters and measurement errors

Dependency	$\psi_{\alpha\beta}$	$\psi_{\gamma\beta}$	$\theta_{e_1e_2}$	$\theta_{e_2e_3}$	$\theta_{e_3e_4}$	$\theta_{e_4e_5}$	$\theta_{e_5e_6}$	$\theta_{e_6e_7}$	$\theta_{e_7e_8}$
Estimate	0,05	0,04	0	0	0,002	0	-0,002	0,01	0,02
Standard error	0,02	0,05	0	0	0,001	0,001	0,001	0	0,01
Estimate / std. error	2,51	0,77	0,69	1,25	2,132	-0,247	-1,796	2,63	2,8
p-value	0,01	0,44	0,49	0,21	0,033	0,805	0,072	0,01	0,01

Source: own elaboration based on SPSS AMOS 21.0.

Part of the correlations obtained for the measurement errors for consecutive observations in time have proven the validity of the relaxation of the assumptions of variance homogeneity and independence. Due to lack of deviation of measurement errors for years: 2003, 2007 and 2008, insignificance of corresponding correlations has appeared. Moreover, lack of dependence may occur due to a disturbance in the homogeneity of the measurement method, claimed by Eurostat for the analysed time series.

Due to overidentification of the structural model, evaluation of fitness is required. The measures of fit for the structural model are presented in table 4 against the statistics of fit of the measurement model.

Table 4. Statistics of measurement and structural models fit of GERD intensity in GDP

Model	χ^2	$\frac{\chi^2}{df}$	GFI	AGFI	NFI	RFI	IFI	TLI	CFI	RMSEA
Measurement model	76	2,95	0,7	0,49	0,93	0,9	0,95	0,95	0,95	0,26
Structural model	33,8	2,11	0,8	0,63	0,97	0,9	0,98	0,97	0,98	0,19

Source: own elaboration based on SPSS AMOS 21.0.

Introducing additional assumptions on the structure of variance and covariance has improved the statistics of fit of the structural model. The value of $\frac{\chi^2}{df}$ statistics below the critical level of 5 indicates a good fit of the model. The value RMSEA coefficient is higher than an accepted value of $0{,}11$ which can be caused by a low number of observations in the sample (equal to 36). The values of GFI and AGFI measures are slightly underrepresented but stay at an acceptable level. Other measures have reached very high values of fit, exceeding the critical level of $0{,}9$.

5.2. Structural model of the dynamics of researchers' employment intensity in the business sector (FTERES)

Table 5 presents estimation parameters of a structural model of logarithmized intensity of researchers employed in the business sector (FTERES) with logarithmic trend. The initial mean level of the measure was at the level $\hat{\mu}_\beta = 0{,}074$, whereas the pace of growth was characterized by the parameter $\hat{\mu}_\alpha = 0{,}004$. For both of these parameters individual deviation was observed, with variances equal to $0{,}002$ for the slope parameter and $0{,}067$ for the initial level.

Table 5. Structural model parameters' statistics of researchers employment intensity the business sector (FTERES)

Model parameters and measurement errors	Parameter estimation statistics				Variance of parameters' estimation statistics			
	Estimate	Standard error	Estimate/ standard error	p-value	Estimate	Standard error	Estimate/ standard error	p-value
$\hat{\mu}_\alpha$	0,05	0,015	3,287	0	0,028	0,01	2,803	0,01
$\hat{\mu}_\beta$	1,03	0,284	3,633	***	1,027	0,283	3,623	***
e_1	0,04	0,016	2,566	0,01	0,021	0,016	1,3	0,19
e_2	0,01	0,005	2,272	0,02	0,029	0,01	2,98	0
e_3	0,01	0,003	2,859	0	0,011	0,004	2,496	0,01
e_4	0,01	0,002	3,064	0	0,012	0,005	2,722	0,01
e_5	0	0,002	2,171	0,03	0,008	0,003	2,762	0,01
e_6	0,01	0,004	2,153	0	0,025	0,008	2,993	0
e_7	0,01	0,004	2,909	0	0,008	0,005	1,73	0,08
e_8	0,03	0,008	3,182	0	0,03	0,011	2,748	0,01

The symbol "***" means the p-value lower than 0,001.
Source: own elaboration based on SPSS AMOS 21.0.

Insignificant measurement errors for years 2005 and 2010 influenced the structure of the covariance matrix. Moreover, changes in the methodology of data measurement for the FTERES indicator were introduced by Eurostat in the analysed period of time[5], which has resulted in the insignificance of the majority of covariances of measurement (see table 6).

Significant but negative relations between the pace of change in time and initial level of the measure suggest that a growth of qualified workforce in the enterprise sector is slower in countries that already share high intensity of those resources, which implies the existence of a saturation level of researchers' employment.

Table 6. Dependencies between model parameters and measurement errors

Dependency	$\psi_{\alpha\beta}$	$\theta_{e_1e_2}$	$\theta_{e_2e_3}$	$\theta_{e_3e_4}$	$\theta_{e_4e_5}$	$\theta_{e_5e_6}$	$\theta_{e_6e_7}$	$\theta_{e_7e_8}$
Estimate	-0,084	0,009	0,01	0	0,003	0,01	-0,001	0,011
Standard error	0,041	0,007	0,01	0	0,002	0,004	0,002	0,006
Estimate / std. error	-2,044	1,245	2,47	-0,69	1,599	2,52	-0,696	1,724
p-value	0,041	0,213	0,01	0,49	0,11	0,012	0,487	0,085

Source: own elaboration based on SPSS AMOS 21.0.

Due to overidentification, fitness was tested for the model (see table 7). The value of RMSEA is slightly too high, and the values of the GFI and AGFI indices are slightly too

[5] Similarly as for two other variables used in the study, in case of the FTERES variable, modifications in measurement method as well as estimated values were introduced by Eurostat.

low for a well-fitting model. However, the value of $\frac{\chi^2}{df}$ statistics, as well as relative fit measures, are satisfying. Having in mind limitations imposed by estimation using a small sample, the presented statistics of fitness are acceptable.

Table 7. Statistics of fit for the measurement and structural models of researchers employment intensity in the business sector (FTERES)

Model	χ^2	$\frac{\chi^2}{df}$	GFI	AGFI	NFI	RFI	IFI	TLI	CFI	RMSEA
Measurement model	106,4	4,09	0,54	0,37	0,87	0,86	0,9	0,89	0,9	0,34
Structural model	51,17	2,84	0,75	0,5	0,94	0,9	0,96	0,93	0,96	0,26

Source: own elaboration based on SPSS AMOS 21.0.

5.3. Structural model of the dynamics of BERD intensity in GDP

The estimation results of a structural model for logarithmized BERD intensity in GDP are presented in table 8. The mean yearly increment is reflected in the value of the slope parameter $\hat{\mu}_\alpha = 0{,}002$, pointing to a slower than linear growth of the trend function of the non-modified measure of BERD intensity in GDP. The initial mean level of the process equalled to $\hat{\mu}_\beta = 0{,}41$. Significant individual deviance of both parameters suggests differentiation of functional forms of change in time among the analysed countries.

Not all measurement errors and their deviations are statistically significant. which is reflected in the values of the covariance matrix of these errors (see table 9), implying the existence of a relation between only selected consecutive measurement errors in time.

Table 8. Structural model parameters' statistics of BERD intensity in GDP

Model parameters and measurement errors	Parameter estimation statistics				Variance of parameters' estimation statistics			
	Estimate	Standard error	Estimate/ standard error	p-value	Estimate	Standard error	Estimate/ standard error	p-value
$\hat{\mu}_\alpha$	0,002	0,001	2,638	0,008	0,003	0,001	2,461	0,014
$\hat{\mu}_\beta$	0,934	0,256	3,651	***	0,962	0,264	3,647	***
e_1	0,026	0,009	2,8	0,005	0,009	0,012	0,733	0,463
e_2	0,02	0,006	3,052	0,002	0,037	0,012	3,146	0,002
e_3	0,003	0,002	1,896	0,058	0,014	0,004	3,208	0,001
e_4	0,007	0,002	2,925	0,003	0,013	0,005	2,383	0,017
e_5	0,003	0,002	1,383	0,167	-0,01	0,008	-1,281	0,2
e_6	0,036	0,011	3,21	0,001	0,014	0,013	1,032	0,302

The symbol "***" means the p-value lower than 0,001.

Source: own elaboration based on SPSS AMOS 21.0.

The structural model points to no relation between the initial level of the process and its slope, meaning no dependency between initial business sector involvement and dynamics of R&D funding. This process is not directly influenced by public intervention in the area of innovation and is a result of individual activity of enterprises. The result suggests no regularity in business involvement stimulated by the policy according to the level of country's business sector innovativeness.

Table 9. Dependencies between model parameters and measurement errors

Dependency	$\psi_{\alpha\beta}$	$\theta_{\varepsilon_1\varepsilon_2}$	$\theta_{\varepsilon_2\varepsilon_3}$	$\theta_{\varepsilon_3\varepsilon_4}$	$\theta_{\varepsilon_4\varepsilon_5}$	$\theta_{\varepsilon_5\varepsilon_6}$
Estimate	-0,001	0,004	0,015	0,007	-0,001	-0,017
Standard error	0,009	0,006	0,005	0,003	0,003	0,008
Estimate / std. error	-0,125	0,599	2,907	2,251	-0,378	-2,031
p-value	0,901	0,549	0,004	0,024	0,705	0,042

Source: own elaboration based on SPSS AMOS 21.0.

Due to overidentification of the model, fitness indices were estimated and introduced in table 10. Low values of RMSEA and $\frac{\chi^2}{\mathrm{d}f}$ statistics as well as high values of other fit measures (most specifically the relative measures RFI, IFI, TLI, CFI) are very satisfying and indicate a good fit of the model.

Table 10. Statistics of measurement and structural models fit of BERD intensity in GDP

Model	χ^2	$\frac{\chi^2}{\mathrm{d}f}$	GFI	AGFI	NFI	RFI	IFI	TLI	CFI	RMSEA
Measurement model	30	2,3	0,75	0,6	0,95	0,94	0,97	0,96	0,97	0,22
Structural model	8,25	1,18	0,92	0,75	0,99	0,97	0,99	0,99	0,99	0,08

Source: own elaboration based on SPSS AMOS 21.0.

6. Final remarks and conclusions

The authors approached modelling macro level innovation dynamics with the use of a method diverging from traditional panel data modelling procedures which allowed to analyze very short time series available for innovation statistics. This has enabled verification of time change characteristics of the innovation process. Setting a matrix of time series in the form of a structural model has led not only to testing the functional forms of the process' dynamics but also to verify the existence of a dependency between change in time and initial level of analyzed measures. Moreover, flexibility of a structural modelling approach allowed to test the functional form of the process independently from the assumptions on measurement error distribution. This property of latent growth curve modelling is not fulfilled by any other research procedure. Furthermore, the possibility to test various covariance structures of measurement errors allowed to discover irregularities arising due to lack of homogeneity in measurement techniques. These characteristics, being a common phenomenon in R&D statistics according to Eurostat [13], are not revealed by any other analytical approach.

Cognitive results indicate that development of innovative economies is a common process, observed at a transnational level. Despite a small sample, influencing the statistics of fit of the models, the measures of this process were described by trend functions common for all considered countries. According to the estimated models, the dynamics of change in the analysed time period is the fastest for GERD intensity in GDP and can be described by a quadratic time trend. This measure reflects the behaviour of all sectors financing R&D, with a big part being public money (outlaid according to policy goals) and BERD expenditures. The process of BERD intensity (logarithmized) is increasing linearly in time, with a parameter implying slower than linear pace for the unmodified indicator, whereas the employment behaviour of researchers in enterprises (logarithmized) has a logarithmic pace of change. This result suggests that the adjustment of the business sector to a common strategy is slower than the dynamics of the policy executed. Moreover, the reaction of enterprises is slower in employment than in financing, which can be caused by a reluctance in introducing change of a more durable character.

Moreover dependency of the process dynamics on the initial level of a country's innovativeness was observed for two out of three considered measures. Lack of dependency between the initial level of BERD intensity and its increment in time may suggest that the financing behaviour of enterprises cannot be easily regulated and is influenced by many factors that impede the strategy of growth. More interestingly, the dependency on the initial status was positive for GERD intensity and negative for the intensity of researchers employed by enterprises. The second relation may imply an existence of a saturation level of qualified workforce. The pace of employment of new qualified workers slows down with the higher engagement of researchers in the business sector of a country. The existence of an employment saturation level of researchers also explains a slower policy reaction of enterprises in employment than in financing. On the other hand, the positive association between GERD intensity initial level and its dynamics may point to the existence of a global innovation race between the most innovative economies. Countries that are highly innovative compete in the process of catching up to the world leaders of innovation (such as Japan, USA, South Korea). This process is often referred to in strategic documents at the European level which aim at Europe becoming "the most competitive, knowledge-based economy in the world" [4].

The obtained results imply an existence of the observed relations only in the selected period of time and for the analysed group of countries. Further work would involve analysing a bigger sample and a longer time series, as well as the introduction of more complex measures of innovation.

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