Structural Equation Modeling in Evaluation of Technological Potential of European Union Countries in the years 2008-2012

Adam P. Balcerzak, Michał Bernard Pietrzak

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Adam P. Balcerzak¹, Michał Bernard Pietrzak²

Abstract
The abilities of countries to take advantage of global technological progress is currently the main growth determinant. It is especially important in the case of developed economies and the countries that concentrate on closing a development gap. As a result, there is a scientific need to make an international comparisons of countries’ technological potential, which can be useful in pointing the economies that can be considered as the leaders and the economies that make especially quick progress in the field. Thus, the main purpose of the research is the identification of the variables that influence countries’ technological potential at macroeconomic level, which can be used in its measuring. The second aim of the article is the evaluation of progress obtained by “new” European Union member states. It is assumed that technological potential can be treated as a latent variable. Thus, it can be measured with application of Structural Equation Models (SEM). In the research, the hypothetic SEM model was proposed for the European Union countries in the years 2008-2012. The model was estimated with application of seven variables sugested by Eurostat as the potential measures of technological potential of the EU economies. The research confirmed significant influence of five of the given variables. Additionally, the research showed some progress in the field obtained by Central European countries that joined the EU after the year 2004.

Keywords: structural equation model (SEM), technology, technological potential, European Union

JEL Classification: C30, C38, O14

1. Introduction
Improvement of technological potential of the economies and their abilities to take advantage of technological progress is currently treated as a fundamental aim of every long term development strategy. It can be found as a pillar of Europe 2020 strategy (see Balcerzak, 2015). Based on the endogenous growth theory and new institutional economics one can point wide range of determinant affecting countries technological potential such as: institutional factors, economic sustainability, quality of human capital, regulations of labour markets (Balcerzak, 2016; 2009; Lechman, 2013; Pietrzak et al., 2014; Gorączkowska, 2015; Balcerzak & Pietrzak, 2016a; 2016b; 2016c; Müller-Frańczek & Pietrzak, 2011; Wilk et al., 2013; Sachpazidu-Wójcicka, 2014), effectiveness of financial markets influencing allocation

¹ Corresponding author: Nicolaus Copernicus University, Department of Economics, ul. Gagarina 13a, 87-100 Toruń, adam.balcerzak@umk.pl.
² Nicolaus Copernicus University, Department of Econometrics and Statistics, ul. Gagarina 13a, 87-100 Toruń, michal.pietrzak@umk.pl.
of capital (Zineker et al., 2016), role of economy in the international production chain (Pietrzak & Łapińska, 2015) or finally macroeconomic policy effectiveness (Balcerzak et al., 2016).

In recent years the researches devote great effort and resources to study factors influencing country’s technological potential and to make international comparisons in that field. As a result, the main aim of the article is the identification of the factors/variables that influence countries’ technological potential at macroeconomic level, which can be used in its measuring. Additionally, the research concentrates on the evaluation of progress obtained by the “new” European Union member states in that field. Based on the assumption that technological potential is a complex latent variable structural equation models (SEM) is applied in the research. The study was done for European Union countries in the period 2008-2012.

2. Short outline of SEM methodology

From the macroeconomic perspective technological potential can be treated as complex and multivariate phenomenon, which can be considered as a latent variable. As a result, structural equations modelling (SEM) can be useful method for its measuring. This method includes confirmatory factor analysis and path analysis commonly used in econometrics. The main advantage of SEM models in the context of application for measuring complex economic phenomena is their high elasticity in comparison to regression models. The SEM models allow to analyse the interrelations between latent variables that are the result of influence of many factors (Bollen, 1989; Kaplan, 2000; Brown, 2006; Pietrzak et al., 2012).

The SEM model consists of an external model and an internal model. The external model represents results of confirmatory factor analysis, which enables to calculate factor loadings for the observable variables forming the latent variable. It is often called a a measurement model. It can be described as:

\[ y = C_y \eta + \varepsilon, \]  
\[ x = C_x \xi + \delta, \]

where: \( y_{pol} \) - the vector of observed endogenous variables, \( x_{pol} \) - the vector of observed exogenous variables, \( C_y, C_x \) - matrices of factor loadings, \( \varepsilon_{pol}, \delta_{pol} \) - vectors of measurement errors.
The internal model consists of equations that describe the interrelations between latent variables. It represents path analysis that enable to specify both direct and indirect casual dependencies between specified factors. The internal model is often called a structural model. It can be described as:

$$ \eta = A\eta + B\xi + \zeta, $$

where: $\eta_{end}$ - vector of endogenous latent variables, $\xi_{exg}$ - vector of exogenous latent variables, $A_{end}$ - matrix of regression coefficients at endogenous variables, $B_{exg}$ - matrix of coefficients at exogenous variables, $\zeta_{end}$ - vector of disturbances.

3. Application of SEM model to measurement of technological potential of EU countries

In current article technological potential is analysed at a macroeconomic level. The analysis is done for 24 EU countries in the years 2008-2012. The short period of the research is the result of data availability for the panel of countries. In the research it is assumed that technological potential of the countries is a latent variable. As a result, an external model based on SEM methodology is proposed. It is assumed that an internal model does not occur. It means that only the confirmatory factor analysis is done. It allows to measure the assumed latent variable. The research is done with application of observable variables that are proposed by Eurostat for measuring of technological potential in the European Union countries at a macroeconomic level. The set of preliminary variables is presented in table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description of Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>Total intramural R&amp;D expenditure (GERD) (euro per inhabitant)</td>
</tr>
<tr>
<td>X2</td>
<td>Share of government budget appropriations or outlays on research and development (% of total general government expenditure)</td>
</tr>
<tr>
<td>X3</td>
<td>High tech export (% of total export)</td>
</tr>
<tr>
<td>X4</td>
<td>Human resources in science and technology (% of active population)</td>
</tr>
<tr>
<td>X5</td>
<td>Patent applications to the European patent office (EPO) by priority year (per 1 million inhabitants)</td>
</tr>
<tr>
<td>X6</td>
<td>Turnover from innovation (% of total turnover)</td>
</tr>
<tr>
<td>X7</td>
<td>Total R&amp;D personnel (per 1 million inhabitants)</td>
</tr>
</tbody>
</table>

**Table 1** Set of preliminary observable variables proposed by Eurostat for measuring technological potential of countries

The hypothetic SEM model was estimated in AMOS v. 16 packet with application of maximum likelihood method. Two preliminary observable variables $X_6$ and $X_7$ were not statistically significant, as a result they were removed from the model. The final model is
presented in Figure 1. Y relates to latent variable and the observable variables are given as $x_i$ ($i=1,2,...,10$). The final results are presented in table 2.

![Hypothetic SEM model for estimation of technological potential in EU countries.](image)

**Fig. 1.** Hypothetic SEM model for estimation of technological potential in EU countries.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Estimate</th>
<th>Standardized estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1$</td>
<td>$\alpha_1$</td>
<td>1</td>
<td>0,989</td>
<td>-</td>
</tr>
<tr>
<td>$X_2$</td>
<td>$\alpha_2$</td>
<td>0,001</td>
<td>0,644</td>
<td>~0,00</td>
</tr>
<tr>
<td>$X_3$</td>
<td>$\alpha_3$</td>
<td>0,005</td>
<td>0,372</td>
<td>~0,00</td>
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<tr>
<td>$X_4$</td>
<td>$\alpha_4$</td>
<td>0,014</td>
<td>0,735</td>
<td>~0,00</td>
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<tr>
<td>$X_5$</td>
<td>$\alpha_5$</td>
<td>0,230</td>
<td>0,960</td>
<td>~0,00</td>
</tr>
</tbody>
</table>

**Table 2.** Estimations of parameters of SEM model based on the confirmatory factor analysis.

The parameters of external model are statistically significant. It confirms that all the observable variables are properly identified. The standardized estimations of parameters given in Table 2 can be used to evaluate the strengths of the influence of the given variable. The variables with the strongest influence can be ordered as follow: $X_1$ - total intramural R&D expenditure. $X_2$ - patent applications to the European patent office (EPO). The variables with the average influence can be ordered as follow: $X_4$ - human resources in science and technology. $X_2$ - share of government budget appropriations or outlays on research and development. The variable $X_3$ is characterised with the weakest influence. Authors arbitrarily specified the strength of impact of variables and their classification to the three given subsets. The two measures are used for assessing an adjustment of the model to the input data: a) the Incremental Fit Index (IFI), b) Root Mean Square Error of Approximation (RMSEA) coefficients. The IFI coefficient equals 0,990 and the RMSEA coefficient equals 0,088. In
both cases the values of the measures are lower than the maximum accepted values of 0.9 for IFI and 0.1 for RMSEA. It confirms proper adjustment of the model to the input data.

<table>
<thead>
<tr>
<th>Latent variable</th>
<th>Observable variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>0.826 1.344 0.52 16.705 0.76</td>
</tr>
</tbody>
</table>

**Table 3. Factor Score Weights.**

<table>
<thead>
<tr>
<th>Country</th>
<th>Latent variable</th>
<th>Class</th>
<th>Rank</th>
<th>Country</th>
<th>Latent variable</th>
<th>Class</th>
<th>Rank</th>
</tr>
</thead>
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<tr>
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<td>5</td>
<td>1</td>
<td>Sweden</td>
<td>2126</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Finland</td>
<td>2100</td>
<td>5</td>
<td>2</td>
<td>Finland</td>
<td>2126</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Denmark</td>
<td>2024</td>
<td>5</td>
<td>3</td>
<td>Denmark</td>
<td>2093</td>
<td>5</td>
<td>3</td>
</tr>
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<td>4</td>
<td>Germany</td>
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<td>4</td>
<td>4</td>
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<td>Austria</td>
<td>1619</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
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<td>4</td>
<td>6</td>
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<td>4</td>
<td>6</td>
</tr>
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<td>7</td>
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<td>1506</td>
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<td>7</td>
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<td>4</td>
<td>8</td>
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<td>9</td>
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<td>2</td>
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<td>Netherlands</td>
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<td>France</td>
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<td>1412</td>
<td>4</td>
<td>9</td>
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<td>10</td>
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<td>11</td>
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<td>947</td>
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<td>12</td>
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<tr>
<td>Estonia</td>
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<td>Estonia</td>
<td>904</td>
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<td>14</td>
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<td>15</td>
<td>Czech Rep.</td>
<td>821</td>
<td>3</td>
<td>15</td>
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<td>16</td>
<td>Lithuania</td>
<td>779</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Latvia</td>
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<td>2</td>
<td>17</td>
<td>Latvia</td>
<td>686</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>Hungary</td>
<td>669</td>
<td>2</td>
<td>18</td>
<td>Hungary</td>
<td>671</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Greece</td>
<td>661</td>
<td>2</td>
<td>19</td>
<td>Poland</td>
<td>668</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>Poland</td>
<td>613</td>
<td>1</td>
<td>20</td>
<td>Greece</td>
<td>650</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>Portugal</td>
<td>601</td>
<td>1</td>
<td>21</td>
<td>Slovak Rep</td>
<td>635</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Slovak Rep</td>
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<td>1</td>
<td>22</td>
<td>Portugal</td>
<td>626</td>
<td>2</td>
<td>22</td>
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<tr>
<td>Bulgaria</td>
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<td>23</td>
<td>Bulgaria</td>
<td>559</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>Romania</td>
<td>435</td>
<td>1</td>
<td>24</td>
<td>Romania</td>
<td>432</td>
<td>1</td>
<td>24</td>
</tr>
</tbody>
</table>

**Table 4 Ranking and grouping of EU countries based on the level of technological potential.**

The level of technological potential in the EU countries in the years 2008-2012 was assessed basing on the sum of product of values of Factor Score Weights, which are given in table 3, and the values of given variables. Then, the countries were ordered starting with the highest value of the obtained indicator for technological potential to the ones with its lowest value. As a result, it was possible to obtain the ratings for analyzed period. Then, the countries
were groped to one of five subsets with application of natural breaks method, where class no 5 groups the countries with the highest technological potential, and class no 1 with the lowest one. The final results are presented in table 4 and figure 2.

![Fig. 2. The level of technological potential in EU countries in the year 2008-2012](image)

The results show that Scandinavian countries are characterised with the highest level of technological potential. In the year 2008 and 2012 Sweden, Denmark and Finland belonged to the fifth class grouping the economies with the highest potential. In class fourth grouping the countries with high potential one can find the “northern old” EU member states such as Germany, France, Austria, United Kingdom and Ireland. Spain and Italy belong to the third class, where one can also find Estonia. Among “new” member states Estonia obtained the best result. It is often stated that relatively good results obtained by this country in many analogous rankings are the consequence of institutional similarity and closeness to Scandinavian countries mainly Finland. Subsets two and one group the countries with much lower level of technological potential. One can find here mainly “new” member states, Portugal and Greece.

Finally, percentage changes of the value of obtained measure of technological potential in the analysed countries in the years 2008-2012 were calculated. The results are presented in table 5. By analogy, also in the case of percentage changes the countries were grouped to one of five classes based on natural breaks method, which can be seen in the figure 3.
<table>
<thead>
<tr>
<th>Country</th>
<th>Percentage difference</th>
<th>Rank</th>
<th>Class</th>
<th>Country</th>
<th>Percentage difference</th>
<th>Rank</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estonia</td>
<td>21.45%</td>
<td>1</td>
<td>5</td>
<td>Hungary</td>
<td>8.68%</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Poland</td>
<td>17.12%</td>
<td>2</td>
<td>5</td>
<td>Netherlands</td>
<td>7.68%</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Slovenia</td>
<td>15.78%</td>
<td>3</td>
<td>4</td>
<td>Sweden</td>
<td>7.54%</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Austria</td>
<td>15.06%</td>
<td>4</td>
<td>4</td>
<td>Czech Rep.</td>
<td>7.37%</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>Belgium</td>
<td>14.73%</td>
<td>5</td>
<td>4</td>
<td>Bulgaria</td>
<td>6.69%</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>14.46%</td>
<td>6</td>
<td>4</td>
<td>Romania</td>
<td>5.58%</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Portugal</td>
<td>12.30%</td>
<td>7</td>
<td>4</td>
<td>Lithuania</td>
<td>5.42%</td>
<td>19</td>
<td>2</td>
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<tr>
<td>Ireland</td>
<td>11.86%</td>
<td>8</td>
<td>4</td>
<td>Greece</td>
<td>3.02%</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>11.49%</td>
<td>9</td>
<td>4</td>
<td>Latvia</td>
<td>2.45%</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Germany</td>
<td>10.96%</td>
<td>10</td>
<td>3</td>
<td>Finland</td>
<td>2.16%</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
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<td>9.68%</td>
<td>11</td>
<td>3</td>
<td>Italy</td>
<td>0.57%</td>
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</tr>
<tr>
<td>Slovak Rep</td>
<td>9.37%</td>
<td>12</td>
<td>3</td>
<td>Spain</td>
<td>-1.09%</td>
<td>24</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5. Percentage changes of the value of measure of level of technological potential in UE countries in the years 2008-2012.

Fig. 3 Changes of the level of technological potential in UE countries in the years 2008-2012.

When one concentrates on the percentage changes of the value of the measure of technological potential in the case Central European countries, one can find an important progress in the field. Estonia, Poland and Slovenia were the first three countries in the ranking with the increase of the value of the measure by more than 21, 17 and 15% respectively. This good result is especially important in the case of Poland, which is the biggest economy in the region. Additionally, six of ten new member states were grouped in the first three classes. Beside the three mentioned leaders there were also Slovak Republic, Hungary and Czech
Republic. Thus, the results confirm a meaningful technological progress obtained by whole Visegrad group.

4. Conclusions

The aim of the analysis was the identification of the variables that influence countries’ technological potential at a macroeconomic level and that can be used in its measuring. Additionally, the article concentrated on the progress obtained by the Central European countries in the field. The applied SEM methodology enabled to reach both of these purposes.

The analysis confirmed that five of seven variables proposed by Eurostat were statistically significant in the proposed SEM model for measuring technological potential of the EU countries. In spite of the fact that Central European countries in the whole period were mainly classified in the sub-sets grouping the economies with the lower technological potential, the analysis of percentage changes of the value of the measure in the years 2008-2012 shows a meaningful progress in the region.

References


