STATISTICS IN TRANSITION new series, June 2025
Vol. 26, No. 2, pp. xxx–xxx, https://doi.org/10.59139/stattrans-2025-xxx
Received – xx.xx.xxxx; accepted – xx.xx.xxxx

The integrity of the innovation process on the example of EU countries: a PLS-SEM approach

Mateusz Borkowski[1]**, Ewa Gruszewska**[2]

Abstract

The purpose of the article is to assess the integrity of the elements of innovation processes and to measure their efficiency based on the Schumpeter trilogy concept. The research was conducted with regard to European Union (EU) countries. The paper applies the partial least squares structural equation modelling (PLS-SEM) method that allows the analysis of latent variables (LVs). On the basis of the PLS-SEM models for 2010 and 2020, it was concluded that innovation processes were proceeding in an integrated manner in EU countries. Not only did the modelling results indicate a positive and moderate effect of the invention inputs LV on the innovation efficiency LV, but also a positive and strong influence of innovation efficiency LV on the innovation diffusion LV in the analyzed countries in both researched years. The technological process integrity of the EU economies was lower in 2020, than in 2010. In order to improve the functioning of innovation activities it is necessary to increase technology inputs and the efficiency of their use in R&D activities. Intensification of the collaboration between scientific and research institutes and entrepreneurs is recommended. The PLS-SEM model made it possible to measure its elements and assess the integrity of technological change.

Key words: the Schumpeter trilogy, innovation, technology diffusion, PLS-SEM

1. Introduction

Innovativeness has been considered as one of the main driving forces of the contemporary economic development. Not only do innovations allow an increase in the productivity of production factors, but also lead to qualitative changes in the economy. Every new technological solution results from an innovation process, which consists of three phases: invention, innovation and imitation – it is the, i.e. the Schumpeter trilogy (Curlee & Goel, 1989, p. 3). The integrity of the indicated elements

[1] Department of Political Economics, Faculty of Economics and Finance, University of Bialystok, Poland, E-mail: m.borkowski@uwb.edu.pl, ORCID: https://orcid.org/0000-0003-0644-4764.

[2] Department of Political Economics, Faculty of Economics and Finance, University of Bialystok, Poland, E-mail: gruszew@uwb.edu.pl, ORCID: https://orcid.org/0000-0002-4943-0250.

of technological change is essential for an innovative activity to generate the greatest benefits in the economy.

The theory of innovation stems from the work of Schumpeter, while research of such scientists as Rogers, Freeman, Rosenberg, Porter, Rothwell, Lundvall or Nelson contributed to this theory development (Fagerberg et al., 2012, p. 1144). The intensive development of research on innovations, the process of their creation and the technology transfer has led innovation theory to become a self-contained stream separated from production theory. It includes both elements of micro- (enterprise and production theory) and macroeconomics (growth and development theory), in addition to those from the field of management (see: Fernández, 2023).

The analysis of the economic data indicates that the rate of creation and implementation of innovations varies among contemporary economies. One can clearly distinguish those economies that are at the top of innovation rankings (innovative leaders) and on the other hand, countries with a low rate of internal innovativeness, that only import new solutions from others or imitate extraneous innovations.

The purpose of the article is to assess the integrity of the elements of innovation processes and to measure their efficiency with regard to the concept of the Schumpeter trilogy (invention, innovation and imitation). The research was conducted on the basis of data from 26 EU economies for the years 2010 and 2020. The paper applies the partial least squares structural equation modelling (PLS-SEM) method that allows the analysis of relationships between latent variables (LVs).

The article consists of three parts. The subsequent section contains a review of relevant and topical literature on innovation, innovativeness and entrepreneurship. The second part includes a presentation of the research methodology applied in the study. This section presents the research method, i.e. the partial least squares structural equation modelling (PLS-SEM), and the econometric specification of PLS-SEM model used in our research. On the basis of literature review and the specified model, two hypothesis have been formulated. The fourth section provides modeling results and discussion. The paper closes with conclusions, in addition to which the limitations of the research and future research directions are specified.

2. Theoretical framework

The theory of innovation has its roots in the works of Schumpeter, who defined innovation not only as the revolutionary introduction of a new product or production method but also as the opening of a new market or even the acquisition of a new source of supply (Schumpeter, 1949, p. 66). The contemporary concept of innovation does not differ significantly from that proposed by Schumpeter. Innovation is new (radical) or improved (incremental) technology solutions (product or business, but also a combination of these) that are significantly different from the previous ones and "*has been introduced on the market or brought into use*" (OECD & European Union, 2018, p. 68).

The process of technological change consists of three subsequent stages. First, there is an idea, which is the result of the application of knowledge and/or technical information to solve a problem. Creativity enables human capital to be transformed into new technical and product or organizational solutions; into inventions that can become innovations. The second stage of technological change is the emergence of innovation. This occurs when there are resources to support new solutions. Therefore, innovation is the first commercial application of a certain set of knowledge. The entity that has the right to use the idea can profit from the practical application of the invention. Successful innovation enables businesses to achieve increasingly high profits, which can contribute to relatively rapid expansion into new markets. "*(I)nnovation is a central determinant of longer-run success and failure for manufacturing firms. Moreover, most industry shattering innovations do not spring from the established competitors in an industry but from new firms or from the established firms entering a new arena*" (Utterback, 1994, p. xxvii).

Proposition 1: *Technology inputs, both financial and human, are essential in increasing the efficiency of the innovation activities of enterprises in the economy.*

The greater the benefits, the faster the next stage of technological, i.e. the diffusion of innovation, will come. It is a process of the continuous spread of a new technological solution across companies, regions or even countries. As Rogers (1983, pp. 34–35) asserts, it is a "*special type of communication concerned with the spread of messages that are new ideas*". Entrepreneurs may attempt to implement external innovations in their own production process of goods and services. This results in the emergence of imitations, which diminish the power of the company that launched a particular innovation on the market. As Kurz (2008, p. 276) wrote: "*In the course of the diffusion process the new methods of production are generalized throughout the system as a whole, thereby establishing a new set of relative prices and gradually eroding the (extra) profits reaped by the innovators and the first generation of followers, while late adopters run the risk of being driven out of the market*".

The diffusion of innovations is inevitable; its cause is the innovative motives of companies and the competitive strength. Imitation processes lead to the better satisfaction of people's needs. The increase in quantities and the reduction in prices of both old and new goods and services enables people to access and use new solutions quicker (Diamond, 2019, p. 65). The diffusion leads to the expansion of benefits achieved from the innovation process. It also contributes to the creation of subsequent generations of technology and products (Vargo et al., 2020, pp. 527–528).

The degree of the diffusion of innovation within highly developed economies is stronger than in other countries (Keller, 2010, p. 806). Nevertheless, the importance of spreading technical solutions to other countries, especially those with medium and low levels of development, cannot be overestimated. In the presence of capital constraints, foreign direct investment may be the only available channel for of new technical solutions and a way to increase efficiency. Positive effects can be achieved by building higher-productivity human capital in foreign companies and then adopting similar solutions in domestic companies (the FDI spillovers through worker rotation).

The diffusion of a new technology is a time- and capital-consuming process. The rate of innovation spread varies and is changing (shortening) dynamically over time due to the progress of communication and information transmission technology advances. The proof of the success of the diffusion process is the occurrence of the horizontal and vertical technology spillovers (Keller, 2010, p. 824). Not every innovation is diffused effectively, which means that only some percentage of new technology solutions completes the innovation process successfully (Dosi & Nelson, 2010, pp. 91–92). Therefore, it is essential that the analysis of the process of technological change include all the three above-mentioned elements. However, nowadays there is a tendency to focus only on the "middle" part of this process (Potts, 2019, pp. 53–54).

Proposition 2: *The ability and propensity to create and implement innovations is a necessary condition for the diffusion of new technological solutions locally and globally.*

The technological process is similar for most new technological solutions, but the reasons why they are created vary. The very first models of the development of innovations indicated that the cause of their emergence could be a supply or demand factor (Rothwell, 1994, pp. 7-9). Innovations could be "pushed" by the science or "pulled" by the market. Over time, linear models were superseded by more complex, non-linear models (the presence of interactions, as well as feedback loops between factors and elements of the technological process), which were a synthesis and development of the previous ones (Ahmed & Shepherd, 2010, pp. 169-172). Subsequent generations of innovation models were based on the belief that new technological solutions are induced by both scientific developments and changes in market needs (Kline & Rosenberg, 1986, p. 290; Rothwell & Zegveld, 1985, p. 50). The high dynamics of innovation processes and the active role of entrepreneurs in the search for optimal solutions in the 21st century led to the formation of a model emphasizing the importance of openness in the innovation process. The essence of open innovation is in the "*purposeful inflows and outflows of knowledge to accelerate innovation internally while also expanding the markets for the external use of innovation*" (Chesbrough, 2006).

Innovativeness, i.e. the ability of enterprises to use existing knowledge to create, implement, and then spread (diffuse) new technological solutions (Salavou, 2004, p. 35), is at the core of entrepreneurship. "*Innovation is the specific instrument of entrepreneurship. It is the act that endows resources with a new capacity to create wealth*" (Drucker, 1993, p. 30).

Entrepreneurship, which is the basis of the entire capitalist world, externalizes itself in a continuous series of disruptive events (Schumpeter, 2003, pp. 82–83). These result from creativity, a willingness to bear risks, openness to change, and curiosity in the search for new technological solutions (Kirzner, 2009, p. 148). Entrepreneurs are the architects of the new order; through the creation of innovation, they continuously revolutionize the economic structure from within, constantly destroying what is old, relentlessly creating new value and quality (Aydin, 2010, p. 21). The emergence of new breakthrough applications of knowledge is the trigger for "*creative destruction*", which clears the market of unnecessary products and inefficient production methods, making room for new, better solutions. Such disruption of the equilibrium causes a tendency for it to reappear, but at a higher level (Dahms, 1995, p. 6). "*If we are open to innovative dynamism and allow entrepreneurs to innovate, we will have bounty. If we are closed to innovative dynamism and bind entrepreneurs, we will have stagnation*" (Diamond, 2019, p. 3).

3. Research methodology

3.1. Research method – PLS-SEM

The article applies structural equation modelling (SEM) as a research method. It is an econometric technique for modelling relationships between latent variables (LVs), that "*makes full use of theoretical and empirical knowledge*" (Skrodzka, 2016, p. 283). In general, two SEM model estimation methods can be distinguished:

- Jöreskog's (1970) covariance based (CB) and
- Wold's (1980) partial least squares based (PLS).

While both methods lead to similar results (Sarstedt et al., 2016, p. 4005), the choice should be supported by substantive and statistical reasons. We decided to choose PLS-SEM instead of CB-SEM on the basis of three main premises (Hair et al., 2011, p. 144; Hair, Matthews, et al., 2017, p. 118): the research uses a small data sample ($N < 100$), indicators do not follow a normal distribution, and the study uses values of latent variables as synthetic measures.

The PLS-SEM proceeds in three subsequent stages (Hair et al., 2016; Hair, Sarstetd, et al., 2017):

- model specification:
  - structural (theoretical, inner) model specification that involves identifying relationships between latent variables in the model;

  - measurement (outer) model specification that consists in determining how latent variables are defined (the selection of observable indicators reflect or form them) in the model;
- estimation – PLS-SEM algorithm involves (Lohmöller, 1989, p. 29): the iterative estimation of the values of weights, the estimation of structural parameters and factor loadings using OLS and the determination of location parameters for both inner and outer relations;
- model verification:
  - substantive validation – coincidence and consistency with theory (initial assumptions) assessment;
  - statistical evaluation, that consists of using verification measures.

In the PLS-SEM, values of latent variables (weighted sums of manifest variables) can be used in subsequent analysis. As they are not original in every estimation, they can be treated as synthetic measures (Ćudić & Skrodzka, 2021, p. 76).

2.2. PLS-SEM model specification and hypothesis evaluation

The structural (inner) model consists of two stochastic equations (1, 2), and includes three latent variables – the level of invention inputs (INP), the innovation efficiency (IE) and the scale of innovation diffusion (ID). The Schumpeter trilogy was the basis for determining both internal and external relations in the applied PLS-SEM model. The level of invention inputs latent variable (INP) was lagged by one year due to the substantive assumption that technology outlays need time to be transformed into innovation effects.

$$\mathrm{IE}_t = \alpha_1 \cdot \mathrm{INP}_{t-1} + \alpha_0 + \varepsilon_t, \tag{1}$$

$$\mathrm{ID}_t = \beta_1 \cdot \mathrm{IE}_t + \beta_0 + \zeta_t. \tag{2}$$

where:

IE_t	is the innovation efficiency in the year t;
INP_{t-1}	is the level of invention inputs in the year t–1;
ID_t	is the scale of innovation diffusion in the year t;
$\alpha_1; \beta_1$	is the structural parameters of the model;
$\alpha_0; \beta_0$	is the location parameters for structural relations;
$\varepsilon_t;\ \zeta_t$	is the random errors (with expected value equal to 0).

All of the latent constructs were defined deductively, which implies that they are reflective in nature. Table 1 contains the final specification of the measurement model. Indicators were chosen on the basis of substantive (theoretical premises) and statistical criteria (the discriminatory abilities of diagnostic variables and the quality of the estimated PLS-SEM model). The statistical data was retrieved from international organizations' databases (Eurostat, ILOSTAT, UNCTAD) for 2010 and 2020. The modelling was performed on the basis of 26 EU economies – Greece was excluded from the research due to substantial data gaps.

Every innovation process starts with invention that requires a certain number of outlays (Ciborowski, 2017, pp. 276–277). This phase is represented by the level of invention inputs latent variable (INP), which is defined by four indicators. Business enterprise R&D expenditures as a % of GDP (INP_1) and government budget allocations for R&D as a % of GDP (INP_2) are related to financial technology inputs, while the percentage of R&D personnel in labour force (INP_3) and the percentage of scientists and engineers in the population aged from 25 to 64 (INP_4) reflect the human contribution to technology development.

Then, invention inputs are transformed into new technology solutions, which are sold and used in business activities. This stage of innovation process is reflected by the innovation efficiency latent variable (IE), which is specified by five diagnostic variables. Not only does the successful innovation activities result in a larger scale of creating technology solutions (IE_1, i.e. the number of patent applications to the EPO per million inhabitants) and higher turnover (IE_2, i.e. the total turnover of innovative enterprises in EUR per one innovative enterprise), but also in higher productivity (Eaton & Kortum, 1999, p. 542) of companies (labour, i.e. IE_3, energy, i.e. IE_4, and resource, i.e. IE_5).

Table 1: The specification of measurement (outer) model

	Description of a diagnostic variable	Data source
The level of invention inputs (INP) latent variable		
INP_1	Business enterprise R&D expenditures (% of GDP)	Eurostat
INP_2	Government budget allocations for R&D (% of GDP)	Eurostat
INP_3	R&D personnel (% of labour force)	Eurostat
INP_4	Scientists and engineers (% of population at the age from 25 to 64 years)	Eurostat
The innovation efficiency (IE) latent variable		
IE_1	Patent applications to the EPO per million inhabitants	Eurostat
IE_2	Total turnover of innovative enterprises (EUR per innovative enterprise)	Eurostat (CIS[a])
IE_3	Labour productivity (output per hour worked)	ILOSTAT
IE_4	Energy productivity (euro per kilogram of oil equivalent)	Eurostat
IE_5	Resource productivity (euro per kilogram used materials)	Eurostat
The scale of innovation diffusion (ID) latent variable		
ID_1	High-tech export (thous. EUR per inhabitant)	Eurostat
ID_2	Foreign Direct Investments, stock outward (thous. USD per capita)	UNCTAD

Note: [a] Community Innovation Survey.

Source: authors' work.

The final phase is imitation, a spread of new and existing technology solutions throughout enterprises located in other regions and countries. This stage is reflected by the scale of innovation diffusion latent variable (ID), that is defined by two indicators. There are two main channels of innovation diffusion (Roszkowska, 2013, p. 58): trade (ID_1 – a value of high technology products exports per capita) and investment (ID_2 – a stock value of outward FDI per capita).

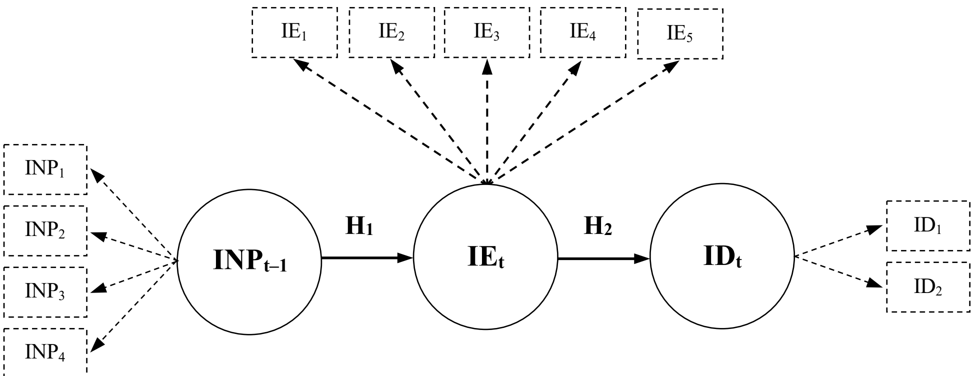

Figure 1: Diagram of the PLS-SEM model applied in this study

Source: authors' work.

The final specification of the applied PLS-SEM model is presented in Figure 1. The hypotheses correspond with propositions, and are formulated as follows:

H1. The level of invention inputs LV correlates with the innovation efficiency LV in a positive, strong (≥ 0.700) and statistically significant ($p < 5\%$) manner.

H2. The innovation efficiency LV correlates with the scare of innovation diffusion LV in a positive, strong (≥ 0.700) and statistically significant ($p < 5\%$) manner.

4. Results and discussion

The measurement model estimates are presented in Table 2. Since all latent variables in the model were defined deductively (reflective indicators), the convergent validity, the internal consistency reliability and the discriminant validity of the measurement model are evaluated (Hair et al., 2019, p. 15). All the factor loading values are above 0.400 and are statistically significant at the level of $p < 5\%$. In addition, the average variance extracted (AVE) values are higher than 50%, indicating their convergent validity. The values of the composite reliability measure are in the interval from 0.600 to 0.950, which confirm the internal consistency reliability of each latent variable. On the basis of cross-loadings analysis, discriminant validity was established. Moreover, the model is coincident and consequently consistent with initial assumptions, which are based on an economic theory. Therefore, the measurement model estimated for 2010 as well as 2020 data can be considered positively verified.

Table 2: The measurement model results

Latent variable	Indicator	Convergent validity				Reliability of internal consistency		Discriminant validity	
		Loadings[a]		Average variance extracted		Composite reliability		Cross loadings	
		≥ 0.400		≥ 0.400		0.600 – 0.950			
		2010	2020	2010	2020	2010	2020	2010	2020
INP_{t-1}	INP_1	0.955***	0.914***	0.901	0.759	0.939	0.926	✓	✓
	INP_2	0.841***	0.825***					✓	✓
	INP_3	0.939***	0.943***					✓	✓
	INP_4	0.825***	0.794***					✓	✓
IE_t	IE_1	0.931***	0.847***	0.717	0.658	0.926	0.905	✓	✓
	IE_2	0.916***	0.873***					✓	✓
	IE_3	0.783***	0.627***					✓	✓
	IE_4	0.709***	0.815***					✓	✓
	IE_5	0.874***	0.869***					✓	✓
ID_t	ID_1	0.941***	0.680**	0.819	0.512	0.901	0.676	✓	✓
	ID_2	0.869***	0.749***					✓	✓

Note: [a] 5,000 samples in bootstrapping procedure; t-Student test; *** p ≤ 0.01; ** p ≤ 0.05
Source: authors' work.

In the model for 2010, the level of invention inputs latent variable (INP) is most strongly reflected by the business enterprise R&D expenditures variable (INP_1; 0.955). The R&D personnel indicator (INP_3; 0.939) is also very strongly correlated with this latent variable. The other two indicators of the INP latent variable, namely INP_2 (0.841; government budget allocations for R&D) and INP_4 (0.825; scientists and engineers in population), reflect its changes in a strong way. The model estimated for 2020 yields similar results. The notable difference is in the manifest variable that is most strongly correlated with this latent construct (INP_3; 0.943).

In the model for 2010, the innovation efficiency latent variable (IE) is reflected by indicator of patent applications to the EPO (IE_1; 0.931) in the strongest way. Changes in the IE latent construct is also very strongly reflected by the changes in the turnover of innovative enterprises (IE_2; 0.916). The correlation of the IE variable with sequentially: IE_5 (0.874; resource productivity), IE_3 (0.783; labour productivity) and IE_4

(0.709; energy productivity) is strong. In the model for 2020, results are slightly different. None of the variables correlate very strongly with the innovation efficiency latent variable (IE). This latent variable is most strongly correlated with the measure of turnover of innovative companies (IE_2; 0.873) and this relationship is strong. IE_5 (0.874; resource productivity), IE_1 (0.847; number of patent applications to EPO per capita) and IE_4 (0.815; energy productivity) also reflect this LV changes in a strong manner. The labour productivity (IE_3; 0.623) has the lowest value of factor loading, indicating that correlation of this measure with the IE latent construct is moderate. Considering the two years analysed, it can be concluded that the increase in innovation efficiency is most strongly reflected in the increase in the turnover of innovative businesses and the rise in the number of patent applications. "*Enterprises increasingly tend to use patent protection as an effect of the incurred costs of R&D and as a necessity to secure the results of their intramural research*" (Ciborowski & Skrodzka, 2020, p. 1360).

The measurement model for 2010 indicates that the scale of innovation diffusion latent variable (ID) is most strongly correlated with the high-tech export indicator (ID_1; 0.941). The FDI variable (ID_2; 0.869) reflects changes in these LV values strongly. However, the results for 2020 are slightly different. Both manifest variables correlate slightly weaker with ID than in 2010. Moreover, the FDI measure (ID_2; 0.749) reflects this LV to a larger degree than hi-tech export variable (ID_1; 0.680).

The increase in the relevance of the FDI measure in reflecting innovation diffusion LV over the years indicates changes in the preferred diffusion channels. Entrepreneurs increasingly often choose to rely on more stable, sustained technology diffusion streams, abandoning the one-off, "contract" ones. The FDI enables companies both to create and to accumulate stable assets abroad. Moreover, the resources build through FDI remain in the recipient country even when the investor withdraws from a particular market. The effects of changes in products, manufacturing processes, labour organization, or customer access channels are not confined to a single company. They create positive externalities, including increasing the competitiveness of domestic companies and thereby raising the pressured innovative changes in other companies. Considering the recent socio-economic events in the world (the COVID-19 pandemic, the war in Ukraine), one can expect an even greater increase in the importance of the investment diffusion channel.

$$\mathrm{IE}_{2010} = 0.683^{***} \cdot \mathrm{INP}_{2009} - 0.174 \qquad \mathrm{R}^2 = 0.467 \quad \Bigg| \quad \mathrm{IE}_{2020} = 0.642^{***} \cdot \mathrm{INP}_{2019} - 0.526 \qquad \mathrm{R}^2 = 0.412 \tag{3}$$

$$\mathrm{ID}_{2010} = 0.798^{***} \cdot \mathrm{IE}_{2010} - 0.431 \qquad \mathrm{R}^2 = 0.637 \quad \Bigg| \quad \mathrm{ID}_{2020} = 0.776^{***} \cdot \mathrm{IE}_{2020} - 0.406 \qquad \mathrm{R}^2 = 0.603 \tag{4}$$

$$\mathrm{Q}^2 = 0.282 \quad \Bigg| \quad \mathrm{Q}^2 = 0.118$$

As the measurement model has been considered to be positively verified, one can proceed to the structural model validation. That consists in the evaluation of collinearity, the significance of path coefficients, and the exploratory and predictive power of internal relations (Hair et al., 2019, pp. 15–16). Formulas (3) and (4) represent the estimation of the structural model. In 2010, the level of invention inputs variable (INP) had a moderate, positive, and statistically significant ($p < 1\%$) impact (0.683) on the innovation efficiency construct (IE). Moreover, the correlation (0.798) between innovation efficiency LV and the scale of innovation diffusion LV was positive, strong, and statistically significant ($p < 1\%$). The exploratory power of the structural model for 2010 can be considered as satisfactory (R^2 values). The general Q^2 (Stone-Geisser's test) value (0.282; 10 blindfolds) indicates that the model has good predictive power.

The structural model estimates for 2020 are relatively similar to those obtained for 2010. The level of invention inputs LV moderately, positively and significantly ($p < 1\%$) influenced (0.642) the innovation efficiency LV. What is more, the scale of innovation diffusion LV depends (0.776) on the innovation efficiency LV – this relationship is strong, positive, and statistically significant ($p < 1\%$). The exploratory power of structural equations is satisfactory. The model has fairly good predictive power ($Q^2 = 0.118$; 10 blindfolds). Therefore, the structural model for both 2010 and 2020 can be regarded as positively verified. On the basis of structural relations it can be concluded that innovation processes in EU countries followed the pattern of Schumpeterian trilogy in the studied period.

Formulated statistical hypotheses can be verified by means of structural model equations. Even though there are conditions for the negative verification of the first hypothesis, due to the minor difference from the assumption, conditionally it can be considered positively verified. The level of invention inputs LV positively correlates with the innovation efficiency LV, approximating a strong (≥ 0.600) and statistically significant ($p < 1\%$) manner both in 2010 and 2020. The second statistical hypothesis is also considered to be positively verified. The innovation efficiency LV corelated with the scale of diffusion LV in a positive, strong (0.700) and statistically significant ($p < 5\%$) manner in 2010 and 2020.

However, it should be also noted, that this integrity of the technological change is getting weaker over time (from 2010 to 2020). It seems this has been caused by the gradual merging of the second (innovation) and third (diffusion) phases of the innovation process. For instance, the joint innovation policy of the European Union makes innovative entities apply for legal protection not in their domestic offices, but directly at the European Patent Office. Hence, not only is obtaining such patent a confirmation of innovation, but also a step towards diffusion into a wider space than a single economy. In addition, due to the high capital intensity of innovation activity, new ideas in the process of transformation into innovations are often financed from foreign sources. This is particularly the case with innovations of great importance to the economy, or with high "profit-creating" potential. Such new solutions arouse the interest of large corporations as early as during their creation. This means that the moment an innovation is implemented, it is already internationalized (diffused). Therefore, it can be concluded that globalization processes have led to the shortening of the Schumpeter trilogy into the Schumpeter dilogy. The shortening of the technological process has been demonstrated by studies of several authors, e.g. (Bento & Wilson, 2016; Ellwood et al., 2017; Fischer et al., 2015).

Table 3: Rankings of the level of latent variables in the model in EU countries

Country	INP_{t-1}			IE_t			ID_t		
	2009	2019	change	2009	2019	change	2009	2019	change
Austria	9.	6.	+3	9.	10.	-1	8.	7.	+1
Belgium	6.	5.	+1	7.	9.	-2	6.	4.	+2
Bulgaria	24.	22.	+2	26.	26.	=	26.	26.	=
Croatia	19.	19.	=	22.	24.	-2	25.	23.	+2
Cyprus	21.	23.	-2	14.	14.	=	4.	5.	-1
Czechia	14.	11.	+3	16.	16.	=	12.	6.	+6
Denmark	2.	2.	=	2.	4.	-2	10.	10.	=
Estonia	13.	13.	=	24.	22.	-2	15.	13.	+2
Finland	1.	3.	-2	11.	11.	=	14.	18.	-4
France	7.	10.	-3	6.	5.	+1	13.	15.	-2
Germany	5.	4.	+1	4.	6.	-2	9.	9.	=
Hungary	18.	18.	=	20.	21.	-1	11.	12.	-1
Ireland	8.	12.	-4	8.	2.	+6	3.	2.	+1
Italy	15.	15.	=	10.	7.	+3	18.	20.	-2
Latvia	22.	25.	-3	18.	20.	-2	24.	19.	+5
Lithuania	17.	20.	-3	23.	23.	=	20.	17.	+3
Luxembourg	4.	8.	-4	1.	1.	=	1.	1.	=
Malta	26.	21.	+5	13.	15.	-2	5.	8.	-3
Netherlands	11.	7.	+4	3.	3.	=	2.	3.	-1
Poland	20.	16.	+4	15.	18.	-3	22.	21.	+1
Portugal	16.	14.	+2	21.	19.	+2	21.	24.	-3
Romania	25.	26.	-1	25.	25.	=	23.	25.	-2
Slovakia	23.	24.	-1	19.	17.	+2	17.	16.	+1
Slovenia	10.	9.	+1	17.	13.	+5	16.	14.	+2
Spain	12.	17.	-5	12.	12.	=	19.	22.	-3

Source: authors' work.

As both the measurement and structural model have been positively verified, one can proceed to the analysis of the values of latent variables. Table 3 presents rankings of the EU countries in terms of latent variable scores in 2010 and 2020.

In 2009, the highest level of invention inputs LV was recorded in Finland, and the lowest in Malta. Meanwhile, in 2019, Sweden was the leader of INP ranking, while Romania was at the end of the list. Two countries changed their ranks notably – Malta progressed from the 26th place in 2009 to 21st in 2019, while Spain moved downwards from the 12th place in 2009 to the 17th in 2019. The improvement of Malta's performance in terms of INP ranking results from the increase in the number of scientists and engineers as a % of population aged from 25 to 64 (INP_4). The reason for Spain's decline in the INP ranking was a major decrease in the government budget allocations for R&D as a % of GDP (INP_2).

In 2010 as well as in 2020, the highest innovation efficiency was reported in Luxemburg, and the lowest in Bulgaria. The biggest IE rank changes were observed in Slovenia (ranked 17th in 2010 and 13th in 2020), and in Ireland (8th in 2010 and 2nd in 2020). Both countries' performance in terms of all of the innovation efficiency LV manifest variables was better in 2020 than in 2010.

Technology diffusion occurred on the largest scale in Luxembourg and on the smallest in Bulgaria, both in 2010 and 2020. Two EU economies achieved a significant progress in the ID ranking, i.e. Latvia (24th rank in 2010 and 19th in 2020) and Czechia (12th in 2010 and 6th in 2020). Both countries achieved higher hi-tech export (ID_1) and outward FDI (ID_2) value per capita in 2020, compared to 2020.

EU countries can be classified into four typological groups on the basis of the results for innovation efficiency (IE) and the innovation diffusion (ID) latent variables:

- **dynamic innovators (technology pioneers)** – countries in which companies achieve high innovation efficiency and large-scale of innovation diffusion ($IE_{it} \geq 0$ and $ID_{it} \geq 0$),
- **internal (local) innovators** – countries in which business entities achieve high innovation efficiency and small-scale of innovation diffusion ($IE_{it} \geq 0$ and $ID_{it} < 0$),
- **innovation intermediaries** – countries in which business entities achieve low innovation efficiency and large-scale of innovation diffusion ($IE_{it} < 0$ and $ID_{it} \geq 0$),
- **imitators** – countries in which businesses achieve low level of innovation efficiency and small-scale of innovation diffusion ($IE_{it} < 0$ and $IE_{it} < 0$)

where: i is the number of EU country (i = 1, 2, 3, …, 26) and t is a year (t = 2010, 2020)

Figure 2 presents the division of EU economies into four typological groups according to their innovation status in 2010 and 2020. In 2010, five countries were classified as dynamic innovators: Belgium, Ireland, Luxembourg, the Netherlands and

Sweden. The internal innovators group was comprised of seven economies: Austria, Denmark, Finland, France, Germany and Italy. Only two EU countries were characterized as innovation intermediaries in 2010, namely Cyprus and Malta. The remaining countries (Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain) were classified as technology imitators.

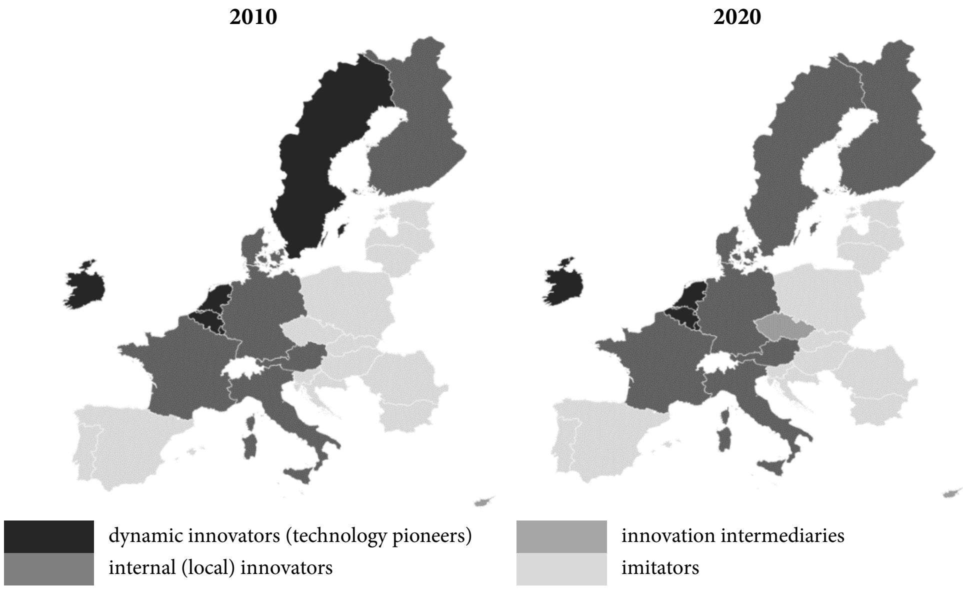

Figure 2: Typological groups of innovation status in 2010 and 2020 among EU countries
Source: authors' work.

The classification of objects in 2020 is similar to the one in 2010. Only three EU economies changed their group throughout the analyzed research period. In 2010, Sweden was among technological pioneers, while in 2020, it belonged to the group of internal innovators. Malta also went down in the ranking: in 2010, it was in the group of innovation intermediates, while in 2020 it descended to the group of technology imitators. The only EU country to improve its innovation status was Czechia, which advanced from imitators to the group of innovation intermediates.

Based on the results, one can observe that countries of Central and Eastern Europe (CEE-11) are much less innovative than other EU economies relatively not long ago (in the 1990s). There are many reasons for this situation. The CEE-11 economies begun to build market economies. The weakness and incompatibility of formal and informal institutions provided a fragile base for entrepreneurship and especially innovative activity. A sound institutional framework is essential in stimulating innovation processes.

Another factor here is comparatively small scale of R&D investment and insufficient involvement of the corporate sector in innovation processes. Based on the Mann-Whitney test[3], significant ($p < 5\%$) differences were identified between the CEE-11 and EU-15 economies for the values of most indicators reflecting invention of inputs in both 2010 and 2020 (Table 4).

Table 4: The average value of invention inputs variables in EU-15 and CEE-11

Countries	INP_1		INP_2		INP_3		INP_4	
	2009	2019	2009	2019	2009	2019	2009	2019
EU-15 (N=15[a])	1.27	1.31	0.70	0.59	1.24	1.49	4.63	7.71
CEE-11 (N=11[b])	0.41	0.72	0.46	0.41	0.68	0.97	3.24	5.49
Mann-Whitney p-value	**0.001**	**0.032**	**0.015**	0.054	**0.003**	**0.005**	**0.027**	**0.003**

Note: [a] Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Malta, the Netherlands, Portugal, Spain, Sweden; [b] Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia
Source: authors' work.

Adequate availability of input streams would make it possible to increase the scale of research in the public and private sectors. Financing of innovation activities could be supported by foreign capital. The demand channel in the creation of innovation is weaker (competition stimulates innovation) due to the limited accumulation capacity of companies. Under such conditions, it may be cheaper to acquire solutions from abroad than to perform research locally. All this causes the CEE-11 countries to predominantly be imitators.

5. Conclusions

The study described in this article concentrated on the assessment of the integrity of the phases of innovation processes and the measurement of their efficiency on the basis of the concept of the Schumpeter trilogy. On the basis of the literature review, two hypotheses were formulated, which were then subjected to verified using an econometric research technique.

The first hypothesis, according to which the level of invention inputs LV correlates with the innovation efficiency in a positive, strong and statistically significant manner, was conditionally positively verified. The level of invention inputs variable (INP) was close to having a strong, positive, and statistically significant ($p < 1\%$) impact on the innovation efficiency construct (IE) both in 2010 (0.683) and 2020 (0.642). The second

[3] Mann-Whitney test is the non-parametric equivalent of the parametric t-Student test. It is used to compare medians, not means, between the nondependent samples. Since the data does not meet the assumptions of a normal distribution, nonparametric tests should be used (Hart, 2001, p. 392).

hypothesis states that the innovation efficiency LV correlates with the scale of innovation diffusion LV in a positive, strong and statistically significant manner. On the basis of the second equation of the structural model, this hypothesis was verified positively. Both in 2010 (0.798) and 2020 (0.776), the PLS-SEM model indicated that the innovation efficiency LV correlates with the scale of diffusion LV in a positive, strong and statistically significant manner. On this basis it can be concluded that in innovation processes in EU economies follow the pattern delineated in the Schumpeter trilogy theory.

Results yielded by the PLS-SEM model were also used to make a typological division of EU countries into four groups in terms of the innovation status. The first group was labelled "dynamic innovators”. These countries that achieve a high degree of efficiency in the innovation process and at the same time export innovative solutions and benefit from it. In this group of countries, the innovation process run in an integrated manner and at an advanced level. The second group (internal innovators) is comprised of those economies that have achieved relatively high innovation efficiency, but a low scale of technology diffusion. Those economies achieve only internal benefits from innovation. Despite the adequate development of innovation processes in the two initial stages of the Schumpeter trilogy, barriers emerge in the last stage that hinder expansion to other countries. The third group (innovation intermediaries) consists of economies that, despite their limited potential for innovation, are exporters of new solutions. These are predominantly small economies that import technology and then resell it, reaping the benefits. Such an activity can, through learning-by-doing, contribute to building a country's intellectual capital and create a basis for its own innovation activity. Such processes mostly concern the services sector (van der Boor et al., 2014, pp. 1595–1596). The countries from the fourth group are characterized by both low innovation potential and low propensity to export innovations to other countries. They are only recipients and imitators of new technologies. Actions that need to be taken to increase the level of innovation should foster the enlargement of the internal potential, as well as the creation of clear channels for the technology transfer into the economy and then out of the country.

Results of this study allowed the identification of the problem of innovative activity of contemporary economies, namely the insufficient scale of innovation inputs. Therefore, it is crucial not only to increase the financial inputs but also the quality of human contribution to innovation processes. It is also necessary to close the gap in education, experience and qualifications. Moreover, it is important to support private channels for funding innovation, as they, compared to public ones, tend to more effective (Ciborowski & Skrodzka, 2019, p. 403). Pro-entrepreneurial attitudes, e.g. openness to change, risk-taking, are of a great importance in innovative activities, and need to be continuously supported by the state. Another problem innovative activity faces in modern economies is the insufficient level of collaboration between R&D centres (such as: universities, technology parks) and enterprises.

The most significant limitation to the research is the low availability of statistical data related to innovative activity. This made it impossible to construct a model based on data on the EU economies for earlier years, i.e. before 2010. A comparison of the modeling results for the later periods, would have allowed more precise conclusions about technological changes in EU countries. Research limitations also resulted from the econometric technique used. Its biggest drawback, apart from the difficulty of calculations without specialised software, is the lack of inter-period comparisons in terms of changes in the values of latent variables. Only increases and decreases in rankings are subject to interpretation, and this results in simplified inferences about changes.

Innovativeness (with its components, changes and determinants), is an important and contemporary topic in the economic theory. The authors' future research will be the continuation of the analyses conducted in the study presented in this article. We plan to conduct a similar study, but one taking into account more countries, also from other parts of the world, to check if one can speak of the integrity of innovation processes in, e.g., Asian countries.

References

Ahmed, P. K., Shepherd, C. D., (2010). Innovation management: Context, strategies, systems and processes. *Pearson*, London.

Aydin, D., (2010). "Destructive" and "Creative" Results of Dynamic Analytical Frameworks of Marx and Schumpeter. *Business and Economics Research Journal*, Vol. 1, No. 2, pp. 17–26.

Bento, N., Wilson, C., (2016). Measuring the duration of formative phases for energy technologies. *Environmental Innovation and Societal Transitions*, Vol. 21, pp. 95–112.

Chesbrough, H., (2006). Open Innovation: A New Paradigm for Understanding Industrial. In H. Chesbrough, W. Vanhaverbeke, & J. West (eds.), Open innovation: Researching a new paradigm. *Oxford University Press*, Oxford, pp. 15–33.

Ciborowski, R., (2017). Territorial transfer of knowledge in terms of creative destruction. *Studies in Logic, Grammar and Rhetoric*, Vol. 50, No. 1, pp. 269–287.

Ciborowski, R., Skrodzka, I., (2019). International Technology Transfer, Innovation and Economic Development of European Union Countries. *European Research Studies Journal*, Vol. XXII, pp. 384–404.

Ciborowski, R., Skrodzka, I. (2020). International technology transfer and innovative changes adjustment in EU. *Empirical Economics*, Vol. 59, pp. 1351–1371.

Ćudić, B., Skrodzka, I., (2021). 'Soft' support infrastructure and the performance of small and medium-sized enterprises in European countries. *Economic Annals*, Vol. 66, No. 230, pp. 67–99.

Curlee, T. R., Goel, R. K., (1989). The Transfer and Diffusion of New Technologies: A Review of the Economics Literature. *Oak Ridge National Laboratory*, Oak Ridge.

Dahms, H. F., (1995). From Creative Action to the Social Rationalization of the Economy: Joseph A. Schumpeter's Social Theory. *Sociological Theory*, Vol. 13, No. 1, pp. 1–13.

Diamond, A. M. J., (2019). Openness to Creative Destruction: Sustaining Innovative Dynamism. *Oxford University Press*, Oxford.

Dosi, G., Nelson, R. R., (2010). Technical Change and Industrial Dynamics as Evolutionary Processes. In B. H. Hall & N. Rosenberg (eds.), Handbook of the Economics of Innovation. *North-Holland*, Amsterdam, pp. 51–127.

Drucker, P. F., (1993). Innovation and Entrepreneurship. Practice and Principles. *Harper Collins Publishers*, New York.

Eaton, J., Kortum, S., (1999). International Technology Diffusion: Theory and Measurement. *International Economic Review*, Vol. 40, No. 3, pp. 537–570.

Ellwood, P., Grimshaw, P. and Pandza, K., (2017). Accelerating the Innovation Process: A Systematic Review and Realist Synthesis of the Research Literature. *International Journal of Management Reviews*, Vol. 19, No. 4, pp. 510–530.

Fagerberg, J., Fosaas, M. and Sapprasert, K., (2012). Innovation: Exploring the knowledge base. *Research Policy*, Vol. 41, No. 7, pp. 1132–1153.

Fernández, I. A., (2023). Innovation and international business: A systematic literature review. *Heliyon*, Vol., 9 No. 1, e12956.

Fischer, C., Lušić, M., Bönig, J., Hornfeck, R. and Franke, J., (2015). Shortening Innovation Cycles by Employee Training Based on the Integration of Virtual Validation into Worker Information Systems. *Procedia CIRP*, Vol. 37, pp. 65–70.

Hair, J. F., Hult, G. T. M., Ringle, C. M. and Sarstedt, M., (2016). A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM). *SAGE Publications*, New York.

Hair, J. F., Matthews, L. M., Matthews, R. L. and Sarstedt, M., (2017). PLS-SEM or CB-SEM: Updated guidelines on which method to use. *International Journal of Multivariate Data Analysis*, Vol. 1, No. 2, pp. 107–123.

Hair, J. F., Ringle, C. M. and Sarstedt, M., (2011). PLS-SEM: Indeed a Silver Bullet. *Journal of Marketing Theory and Practice*, Vol. 19, No. 2, pp. 139–152.

Hair, J. F., Risher, J. J., Sarstedt, M. and Ringle, C. M., (2019). When to use and how to report the results of PLS-SEM. *European Business Review*, Vol. 31, No. 1, pp. 2–24.

Hair, J. F., Sarstetd, M., Ringle, C. M. and Gudergan, S. P., (2017). Advanced Issues in Partial Least Squares Structural Equation Modeling. *SAGE Publications*, New York.

Hart, A., (2001). Mann-Whitney test is not just a test of medians: Differences in spread can be important. British Medical Journal, 323(7309), 391–393.

Jöreskog, K. G., (1970). A General Method for Estimating a Linear Structural Equation System*. *ETS Research Bulletin Series*, Vol. 1970, No. 2, pp. 1–41.

Keller, W., (2010). International Trade, Foreign Direct Investment, and Technology Spillovers. In B. H. Hall & N. Rosenberg (Eds.), Handbook of the Economics of Innovation. *North-Holland*, Amsterdam, pp. 793–829.

Kirzner, I. M., (2009). The alert and creative entrepreneur: A clarification. *Small Business Economics*, Vol. 32, No. 2, pp. 145–152.

Kline, S. J., Rosenberg, N., (1986). An Overview of Innovation. In R. Landau & N. Rosenberg (Eds.), The Positive Sum Strategy: Harnessing Technology for Economic Growth. *National Academy Press*, Washington. pp. 275–307.

Kurz, H. D., (2008). Innovations and profits: Schumpeter and the classical heritage. *Journal of Economic Behavior & Organization*, Vol. 67, No. 1, pp. 263–278.

Lohmöller, J.-B., (1989). Latent Variable Path Modeling with Partial Least Squares. *Springer*, Berlin.

OECD, European Union, (2018). Oslo Manual 2018: Guidelines for collecting, reporting and using data on innovation.

Potts, J., (2019). Innovation Commons: The Origin of Economic Growth. *Oxford University Press*, Oxford.

Rogers, E. M., (1983). Diffusion of Innovations. *The Free Press*.

Roszkowska, D., (2013). Approaches to International Technology Transfer Measurement – An Overview. *Optimum. Studia Ekonomiczne*, Vol. 5, No. 65, pp. 51–63.

Rothwell, R., (1994). Towards the Fifth-generation Innovation Process. *International Marketing Review*, Vol. 11, No. 1, pp. 7–31.

Rothwell, R., Zegveld, W., (1985). Reindustrialization and Technology. *Longman*, London.

Salavou, H., (2004). The concept of innovativeness: Should we need to focus? *European Journal of Innovation Management*, Vol. 7, No. 1, pp. 33–44.

Sarstedt, M., Hair, J. F., Ringle, C. M., Thiele, K. O. and Gudergan, S. P., (2016). Estimation issues with PLS and CB-SEM: Where the bias lies! *Journal of Business Research*, Vol. 69, No. 10, pp. 3998–4010.

Schumpeter, J. A., (1949). The theory of Economic Development. *Harvard University Press*, Cambridge.

Schumpeter, J. A., (2003). Capitalism, Socialism and Democracy. *Routledge*, London.

Skrodzka, I., (2016). Knowledge-Based Economy in the European Union: Cross-Country Analysis. *Statistics in Transition*, Vol. 17, No. 2, pp. 281–294.

Utterback, J. M., (1994). Mastering the Dynamics of Innovation: How Companies Can Seize Opportunities in the Face of Technological Change. *Harvard Business School Press*, Cambridge.

van der Boor, P., Oliveira, P. and Veloso, F., (2014). Users as innovators in developing countries: The global sources of innovation and diffusion in mobile banking services. *Research Policy*, Vol. 43, No. 9, pp. 1594–1607.

Vargo, S. L., Akaka, M. A. and Wieland, H., (2020). Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective. *Journal of Business Research*, Vol. 116, pp. 526–534.

Wold, H., (1980). Soft modelling: Intermediate between traditional model building and data analysis. *Banach Center Publications*, Vol. 6, No. 1, pp. 333–346.