Wiadomości Statystyczne. The Polish Statistician, 2024, *69*(8), 19–42 https://doi.org/10.59139/ws.2024.08.2
Statystyka w praktyce / Statistics in practice
Zgłoszony/submitted: 5.02.2023, poprawiony/revised: 28.02.2024, zaakceptowany/accepted: 25.05.2024

The application of a panel PLS-SEM model to determine the relationship between the institutional factors and the innovativeness of EU economies

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Abstract. The ability of domestic enterprises to invent, introduce and diffuse innovations has been a driving force of the development of modern economies. This paper focuses on the institutional determinants of innovativeness of European Union economies. Institutions are defined as a universal, relatively persistent set of social norms rooted in society, shaping both human behaviour and all relations in the economy. The institutional factors seem to be especially significant nowadays, in an era dominated by the open innovation model. The aim of the study discussed in the article is to measure the quality of institutions and the level of innovativeness of EU economies (26 EU economies, excluding Greece due to data deficiency) and to identify the relationship between these directly unobservable categories. The research applies the partial least squares structural equation modelling (PLS-SEM) method. On the basis of data for the years 2010 and 2020 extracted from Eurostat, Freedom House, the Fraser Institute, the Heritage Foundation and the Legatum Institute, a panel PLS-SEM model was constructed and an empirical analysis was performed. The latter demonstrates that the correlation between the quality of institutions and the level of innovativeness of EU economies was positive, strong and statistically significant both in 2010 and in 2020. Taking into account the theoretical aspects and the results of research of other scientists, this relationship might be considered not only as correlational, but also as causal.

Keywords: innovation, institutions, European Union countries, PLS-SEM model
JEL: C33, C50, O11, O30, O43

Zastosowanie panelowego modelu PLS-SEM do określenia związku między czynnikami instytucjonalnymi a innowacyjnością gospodarek UE

Streszczenie. Zdolność krajowych przedsiębiorstw do tworzenia, wprowadzania oraz rozpowszechniania innowacji jest siłą napędową rozwoju współczesnych gospodarek. W niniejszym artykule skoncentrowano się na instytucjonalnych determinantach innowacyjności gospodarek Unii Europejskiej, przy czym są tu rozumiane jako uniwersalny, względnie trwały zespół norm społecznych, zakorzeniony w społeczeństwie, kształtujący zarówno zachowania ludzi, jak i wszelkie relacje w gospodarce. Czynniki instytucjonalne wydają się szczególnie istotne

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obecnie, w dobie dominującego modelu otwartych innowacji. Celem badania omawianego w artykule jest pomiar jakości instytucji oraz poziomu innowacyjności gospodarek UE (26 krajów, bez Grecji, wyłączonej z powodu braków danych statystycznych) oraz identyfikacja związku występującego pomiędzy tymi bezpośrednio nieobserwowalnymi kategoriami. W badaniu zastosowano modelowanie równań strukturalnych estymowanych cząstkową metodą najmniejszych kwadratów (ang. *partial least squares structural equation modelling* – PLS-SEM). Na podstawie danych za lata 2010 i 2020, udostępnionych przez Eurostat, Freedom House, Fraser Institute, Heritage Foundation i Legatum Institute, skonstruowano panelowy model PLS-SEM i przeprowadzono analizę empiryczną. Wynika z niej, że jakość instytucji pozytywnie, bardzo silnie i statystycznie istotnie korelowała z poziomem innowacyjności gospodarek UE zarówno w 2010 r., jak i w 2020 r. Biorąc pod uwagę aspekty teoretyczne, a także wyniki badań innych naukowców, związek między tymi kategoriami można uznać nie tylko za korelacyjny, lecz także za przyczynowy.

Słowa kluczowe: innowacje, instytucje, kraje Unii Europejskiej, model PLS-SEM

1. Introduction

Contemporarily, innovativeness is considered one of the most important factors determining economic growth. The ability of domestic enterprises to invent, introduce and diffuse innovations has been the driving force of the development of modern economies (Kogan et al., 2017). New technological solutions lead to higher production efficiency. Not only are new products (and services) created faster, but also at a lower production cost. In this context, therefore, it is important to explore the factors of the innovativeness of an economy.

This paper focuses on the institutional determinants of innovativeness of contemporary EU economies. The author defines institutions as a universal, relatively persistent set of social norms rooted in society, shaping both human behaviour and all relations in the economy. By improving the flow of information, institutions reduce the risks and uncertainties of business operations. They also define the rules for conflict solving and cooperation. But most importantly, institutions create incentives for innovative activities. Their essence in the economy is to create a relatively safe field for innovative business activities. Institutional factors seem to be crucial nowadays, in an era dominated by the open innovation model.

The aim of the study discussed in the article is to measure the quality of institutions and the level of innovativeness of EU economies and to identify the relationship between these directly unobservable categories. To achieve the research objective, the partial least squares structural equation modelling (PLS-SEM) technique was applied. Thus, a panel PLS-SEM model measuring the dependency of the level of innovativeness on the quality of institutions was constructed. The research is exploratory in nature. Its novelty lies in the concept of measuring innovativeness, the quality of institutions and the relationship between them, as well as in the panel generalisation of PLS-SEM for a macroeconomic analysis.

2. Theoretical framework

The term *innovation* is commonly known in the economic theory. It was introduced in 1911 by Schumpeter (1949, p. 66) as: (1) the introduction of a new product or (2) production method; (3) opening up of a new market; (4) obtaining a new source of supply of new raw materials or intermediate products and (5) the introduction of a new production organisation. The present concept of innovation is not significantly different from that proposed by Schumpeter. According to the *Oslo Manual 2018* (Organisation for Economic Co-operation and Development [OECD] & Eurostat, 2018, p. 68), innovation is 'a new or improved product or business process (or combination of thereof) that differs significantly from the firm's previous products or business processes and that has been introduced on the market or brought into use by the firm'.

Every new technology solution is the result of a specific innovation process, which always consists of three main phases: invention, innovation and imitation (diffusion). These three elements are referred to as the Schumpeterian triad of innovative change (Schumpeter, 1939, pp. 91–96). The first stage involves the creative development of a new technological solution. At this stage, certain material, financial and human resources are required (Ciborowski, 2017, pp. 276–277). Invention becomes innovation through implementation, that is, through sales that leads to windfall profits, or application in the production process that results in higher productivity and lower production costs (Mohnen & Hall, 2013, p. 51). The final phase involves the spread (diffusion) of new technological solutions across companies, regions and even economies (Rogers, 1983, pp. 5–6).

Since the 1950s, the approach to defining the course of the innovation process has clearly evolved. The 1st (*technology push*) and the 2nd (*market push*) generation models assumed that this process is linear in nature and proceeds in sequential phases (Rothwell, 1994, pp. 7–9). Simple linear innovation process patterns have been superseded over time by non-linear, more complex ones (Gardocka-Jałowiec, 2015, p. 43). The models of the 3rd generation, referred to as the *coupling* (Rothwell & Zegveld, 1985, p. 50), and the 4th generation, defined as *integrated* or *chain-linked* (Kline & Rosenberg, 1986, p. 290), provided a synthesis and development of the previous ones. The basis for the creation of innovation in these models was the constant interaction and interpenetration (the presence of feedback loops) of supply (technological) and demand (market) factors.

The *network* innovation process is the 5th generation model. It emphasises the increasing role of links between entities and their cooperation in developing and introducing new technological solutions (Ahmed & Shepherd, 2010, p. 173). The dynamic technological processes taking place in the 21st century have led to the formation of the 6th generation *open* innovations model (Taferner, 2017, pp. 53–54).

Its essence lies in the use of 'purposeful inflows and outflows of knowledge to accelerate innovation internally while also expanding the markets for the external use of innovation' (Chesbrough, 2006). Open innovation requires the removal or reduction of the organisational barriers that exist between entities and the involvement of strong institutions that provide a safe field for interaction.

Innovativeness is a concept derived from innovation, and in macroscale, it is the ability and propensity of entities operating in the economy to develop, introduce and diffuse innovations (Garcia & Calantone, 2002, pp. 112–117; Subramanian, 1996, p. 224). Innovation has an important function in the development and dynamism of modern world economies. They shatter the existing economic order by inducing a process of 'creative destruction'. Its role is to clear the market of unprofitable companies and redundant products so that, over time, even more technologically advanced companies and products can be created, enabling the economy to move on to a higher growth and development path (Zagóra-Jonszta, 2015, p. 26).

Institutions do not belong to a group of categories that are easy to define. The social science theory distinguishes three main approaches to understanding this concept. The first one assumes that institutions are norms that are embedded in a society and affect all processes occurring in the economy (process approach). The second approach reduces the meaning of institutions only to organisation (entity approach). The last one is a synthesis of the previous two: both social norms and organisations are treated as institutions (process-entity approach), following Hodgson's (2019, p. 226) statement that: 'every organization is an institution, but not every institution is an organization'.

This article applies the process-based definition of institutions, according to which, they are relatively persistent, common, both constituted and spontaneous social norms (customs, patterns, rules and constraints) that are embedded in society, shaping human behaviour and relations in the economic, social, political and legal spheres. The proposed definition assumes that there are two main groups of institutions based on: (1) formal, constituted rules and (2) strongly rooted, not written, spontaneous informal norms (North, 1992, p. 447). The two groups of institutions differ significantly from each other. Formal institutions emerge exogenously from society, as conscious creations of human activity. Usually, they take the written form with a well-defined duration time, which makes them subject to change within a short period of time. Compliance with formal rules is coercive; any deviation from the norms is punishable by sanctions (Yami et al., 2009, p. 154). By contrast, informal institutions emerge spontaneously, as unwritten social customs that are strongly rooted in society (Helmke & Levitsky, 2004, p. 727). Their strong embeddedness in people's mentality implies that the dynamics of their change is relatively low (Williamson, 2000, p. 597). Compliance with informal rules derives from the social responsibility of the individual. Disobeying such norms can lead to the loss of reputation or social exclusion (Tomass, 2012, pp. 720–721).

The impact of institutions on business activity that is a core element of the innovativeness of the economy is unquestionable. Institutions increase the predictability of individuals' behaviour by providing information and improving its flow (Edquist & Johnson, 2005, p. 52). They reduce both the uncertainty and risk associated with entities' operations. Social norms act as a guide in acquiring new knowledge (Gancarczyk, 2002, p. 98). Institutions also significantly reduce the opportunistic behaviour of entities operating in the economy. By defining acceptable solutions, providing opportunities and also setting boundaries, they create a relatively safe field for entities' interaction (Gruszewska, 2013, p. 136). Institutions reduce conflicts and facilitate their resolution. Ultimately, their high quality leads to lower transaction costs (Dobler, 2011, p. 21), and these can be very high in the area of innovative activity.

Institutions ensure the preservation of the competition order. By safeguarding property rights (especially intellectual ones) and regulating economic activity, they protect the economic freedom of individuals. Rules of entrepreneurial activity, i.e. norms connected to starting, running and closing a business, create a secure framework for economic activity (Bal-Woźniak, 2012, p. 158). Institutions generate incentives for innovative activities (Alexander, 2012, pp. 793–795; Chlebna & Simmie, 2018, pp. 972–973; Edquist & Johnson, 2005, pp. 53–55; Wang, 2013, pp. 128–130) by: (1) creating preferential conditions for innovative entities; (2) impacting the flow and allocation of production resources to innovative industries; (3) enabling temporary monopolisation of innovative solutions; (4) reducing the costs of invention failure; (5) stimulating economic activity and increasing individuals' propensity for innovative actions and (6) removing and reducing barriers to cooperation. The indicated channels of institutions' influence on the economy enable companies to undertake activities on an increasingly large scale, becoming factors of entrepreneurship and innovativeness. Misiura and Rozkwitalska (2019, p. 53) note that 'formal and informal institutions are of key importance in providing favourable conditions for innovation in economy'.

By contrast, institutions can also hinder innovation. As the pace of technological changes becomes greater than institutional transformation, a dissonance between institutions and innovation processes may appear. Formal institutions may not be able to adjust to the rapidly changing technology, thus limiting its further development. Moreover, people with their own habits and values (informal rules) might not be interested in the innovative solutions. The lack of internal institutional cohesion[1] can also be a barrier to innovation activities. Not only may the lack of institutional mismatch limit the willingness to create new solutions, but also reduce the benefits of the technological changes that have already been introduced.

[1] Institutional cohesion is the state of an institutional system in which the norms belonging to it do not generate conflicting, sometimes even opposing, incentives.

3. Research method

3.1. The PLS-SEM method

The research is based on structural equation modelling (SEM). SEM models enable the identification of the statistical relationship between latent constructs that are measured through a set of observable indicators (Ćudić & Skrodzka, 2021, pp. 73–74). There are two main estimation methods of SEM models: covariance-based (CB) and partial least squares (PLS). Both methods differ in terms of e.g. the initial requirements of diagnostic variables, the sample (population) size, the estimation procedure, the verification phase. However, they ultimately lead to similar results, which is why they are nowadays considered complementary to each other, rather than competitive concepts (Sarstedt et al., 2016, p. 4005). The decision whether to use CB-SEM or PLS-SEM depends on (Hair et al., 2011, p. 144; 2017, p. 118):

- the normality of the distributions of selected manifest variables – if the distributions are normal, both CB-SEM and PLS-SEM can be used; if the distributions are not normal, PLS-SEM is used rather than CB-SEM;
- the minimum sample (population) size – if the sample size is over 100, both SEM methods can be applied; if the sample size is rather small, PLS-SEM should be used (minimum sample size in PLS-SEM models is equal to 10 times the number of exogenous variables of the most complex OLS in a structural model or formative outer sub-model);
- the construction of the SEM model – if the model consists of latent variables defined only reflectively or formatively, both PLS-SEM and CB-SEM can be used; if the model simultaneously consists of constructs defined both reflectively and formatively, PLS-SEM should be applied;
- the use of latent variable values as synthetic measures – if these values are not planned to be used for linear ordering or in other cases (further analysis), both CB-SEM and PLS-SEM can be applied, otherwise PLS-SEM should be used.

PLS-SEM was developed by Wold (1980) as an alternative to the restrictive Jöreskog (1970) CB-SEM technique. Every PLS-SEM model consists of two sub-models: a structural (inner) one and a measurement (outer) one. The first sub-model represents the relationships between latent variables. The second one defines the relationships between latent variables and the manifest variables that define them. There are two types of relationships in the measurement sub-model: formative and reflective. Latent constructs based on formative relations are weighted sums of the indicators that define them. Reflective relations identify the linear correlation between latent variables and their manifest variables (Lohmöller, 1989, p. 29).

There are two approaches to defining latent constructs in the measurement sub-model: deductive, which assumes that manifest variables reflect the changes in the values of the latent variables (reflective measurement sub-model) and inductive, which implies that manifest variables form the latent constructs (formative measurement sub-model). The decision whether to specify constructs deductively or inductively, depends on (Hair et al., 2016, p. 52):

- the nature of constructs – if a latent variable explains the indicator, the construct should be reflective; if the latent variable is a combination of indicators, the model should be formative;
- the nature of indicators – if an indicator is an output of a latent variable, the latent variable should be defined reflectively; if an indicator is an input of a latent variable, the latent variable should be specified as formative;
- the substitutability of indicators – if indicators are substitutive for each other, the latent variable should be specified as reflective; if they are not, the model should be defined formatively.

The choice of defining latent variables impacts the estimation, statistical verification and interpretation of the measurement sub-model. In the deductive approach, the values of the factor loadings are subject to interpretation, while in the inductive one the values of weights are interpreted (Müller et al., 2018, p. 253). To verify whether the defining of latent variables is correct, confirmatory tetrad analysis (CTA) can be used (Gudergan et al., 2008). The latent construct is correctly defined if no less than 80% of the tetrad values are statistically insignificant (Hair et al., 2017, pp. 94–95).

The PLS algorithm is applied to estimate PLS-SEM models. It consists of four consecutive steps (Henseler et al., 2012; Rogowski, 1990): (1) iterative estimation of weight values; (2) calculation of the values of latent variables using weighting relations; (3) estimation of the factor loadings and structural parameter (path coefficients) values using OLS and (4) computation of the location parameters. Every estimated PLS-SEM model is subject to validation. The substantive verification involves testing the consistency of the model with the theory (initial assumptions) and determining whether it is coincidental. In contrast, statistical validation necessitates the use of statistical measures of model quality. The author's proposed criteria for macro-economic PLS-SEM models are presented in Table 1.

Table 1. Proposed verification measures of PLS-SEM macroeconomic model and their criteria

Verification criteria	Verification measure	Desirable value
Reflective measurement model (deductive approach) – reflective indicators		
Convergent validity	factor loading values	≥ 0.400
	p-value[a]	< 0.001
	average variance extracted (AVE)	≥ 0.500
Internal consistency	Cronbach's alpha (Cb-α)	0.600 ≤ Cb-α ≤ 0.950
	composite reliability (pc)	0.600 ≤ pc ≤ 0.950
Discriminant validity	heterotrait-monotrait ratio (HTMT)	< 0.900
	HTMT confidence interval (95%)	∉ 1.000
Formative measurement model (inductive approach) – formative indicators		
Convergent validity	redundancy analysis	≥ 0.700
Collinearity	variance inflation factor (VIF)	< 5.000
Significance of weights	*p*-value[a]	< 0.001
Structural model		
Collinearity	VIF	< 5.000
Explanatory power	determination coefficient	lack of standard
Predictive power	value of Stone-Geisser test (S-G)	≥ 0.000
Significance of path coefficient	*p*-value[a]	< 0.001

a *t*-Student significance test.
Source: author's work based on Hair et al. (2019) and Sarstedt et al. (2017).

In PLS-SEM latent construct values (q_i), estimated on the basis of the weighting of the relations of the measurement sub-model, are not original in every estimation, which implies that they can be treated as synthetic indicators (Skrodzka, 2016, p. 283). The obtained synthetic variables themselves do not contain an economic interpretation, although they can be used for linear ordering and group discrimination of the researched objects. In the study, a typological division into four groups based on arithmetic mean (equal to 0) and standard deviation (equal to 1) was applied (Skrodzka, 2018, pp. 301–302):

- a very high level of the latent variable: $q_i > 1$;
- a high level of the latent phenomenon: $0 < q_i \leq 1$;
- a moderate level of the unobservable phenomenon: $-1 < q_i \leq 0$;
- a low level of the latent variable: $q_i \leq -1$.

The study applies the panel generalisation of the macroeconomic PLS-SEM model,[2] which is widely used in 'traditional' econometrics. The essence of this approach is to

[2] The first panel generalisation in macroeconomic PLS-SEM models was introduced by Rogowski (1990, pp. 120–121). Its essence is to reduce panel data to cross-section or time series data using e.g. averaging (Ciborowski & Skrodzka, 2019).

treat the panel as a set of cross-sectional data arranged in a stack (panel as a pile of cross-sectional data). The advantages of this technique are:
- ease of use;
- the possibility of maintaining or even increasing the number of observations (it is especially important in PLS-SEM models based on macroeconomic data);
- the ability to investigate changes over time in the values of latent variables in a more effective way.

The literature provides many methods for panel analysis in PLS-SEM (Mohd Ghazali et al., 2023), although none of them enable the proper analysis of changes in the values of latent variables over time and an increase in the number of observations (objects) in the case of small populations.

3.2. Specification of the applied PLS-SEM model

The study explores the relationship between institutions and innovativeness of EU economies. The structural (inner) sub-model consists of a single equation (1) with two latent variables – the level of innovativeness (INN), which is a first-order endogenous construct, and the quality of institutions (INST), which is a first-order exogenous variable:

$$\mathrm{INN}_t = \alpha_1 \mathrm{INST}_t + \alpha_0 + \varepsilon_t, \tag{1}$$

where:
INN_t is the level of innovativeness in year *t*,
INST_t is the quality of institutions in year *t*,
α_1 is the structural parameter of the model,
α_0 is the location parameter for the structural relation,
ε_t is the random error (with expected value equal to 0).

Both of the latent variables (INN and INST) in the applied PLS-SEM model were defined deductively, which means that they were, as theoretical notions, a starting point to empirical data search (Ciborowski & Skrodzka, 2020, p. 1357). This implies that both latent constructs are reflective in nature. The selection of indicators defining latent variables was carried out on the basis of substantive and statistical criteria (the discriminatory ability of diagnostic variables was tested: classical coefficient of variation higher or equal to 10% and the statistical quality of the estimated model was taken into account).

The final specification of the measurement (outer) sub-model is presented in Table 2. The statistical data were extracted from Eurostat and selected statistical organisations that provide institutional measures: Freedom House, the Heritage Foundation, the

Fraser Institute and the Legatum Institute and refer to the EU economies (macroeconomic data). The panel PLS-SEM model considers data from 2010 and 2020[3] (the stack of cross-sectional data) for 26 EU economies (objects of the research in two research years; $N = 52$); Greece was excluded from the research due to a large amount of data missing. The statistical population includes the countries that are currently members of the EU.

Table 2. Specification of the measurement (outer) model

Diagnostic variable	Unit	Source of data
	INST latent variable[a]	
$INST_1$ – rule of law	<–2.50; 2.50>	Freedom House
$INST_2$ – integrity of the legal system	<0.00; 10.00>	Fraser Institute
$INST_3$ – property rights	<0.00; 100.00>	Heritage Foundation
$INST_4$ – business regulations	<0.00; 10.00>	Fraser Institute
$INST_5$ – business freedom	<0.00; 100.00>	Heritage Foundation
$INST_6$ – interpersonal trust		Legatum Institute
$INST_7$ – organisational trust[b]		
$INST_8$ – social networks		
	INN latent variable	
INN_1 – gross domestic expenditure in the business enterprise sector	euro per inhabitant	Eurostat
INN_2 – R&D personnel	% of labour force	
INN_3 – innovative enterprises	% of total number of enterprises	Eurostat (community innovation survey)
INN_4 – patent applications to the European Patent Office	number per million inhabitants	Eurostat
INN_5 – gross value added in professional, scientific and technical activities[c]	% of GDP	
INN_6 – total turnover of innovative enterprises		Eurostat (community innovation survey)
INN_7 – high-tech product export	euro per inhabitant	Eurostat

a All indicators of the INST latent variable are synthetic in nature. b The indicator was originally called 'Institutional trust', although in this study organisations are not institutions. c Full name: gross value added in professional, scientific and technical and administrative and support service activities.
Source: author's work.

The INST variable, which represents the quality of institutions is defined by eight indicators. The assessment of the quality of institutions is based on the use of synthetic institutional measures developed by international statistical organisations (Borkowski, 2021, p. 24; Kunčič, 2014, p. 43). Three variables: rule of law ($INST_1$), integrity of the

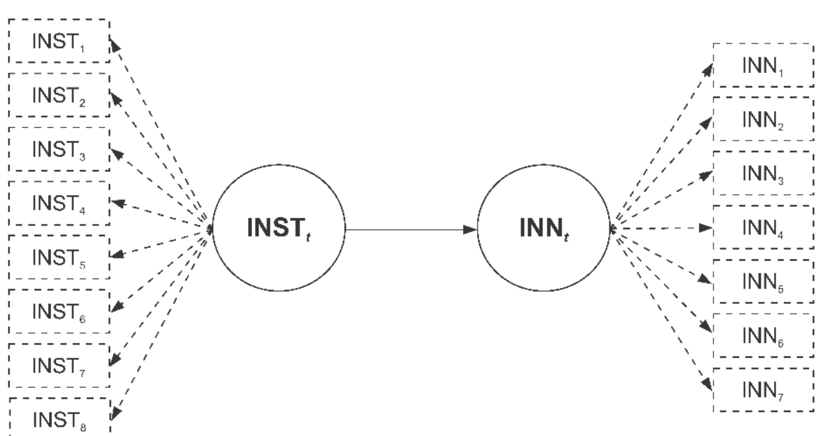
[3] The choice of 2010 and 2020 was determined by the availability of statistical data and willingness to measure changes in latent variable values over at least 10 years.

legal system ($INST_2$) and property rights ($INST_3$) concern the quality of legal norms. Two further variables: business regulations ($INST_4$) and business freedom ($INST_5$) are connected to the quality of business activity regulations. The last three measures of this latent variable: interpersonal trust ($INST_6$), organisational trust ($INST_7$) and social networks ($INST_8$) are proxies of the quality of informal institutions. The diagnostic variables reflect the quality of both formal (rule of law, property rights, business regulations, and also general economic freedom) and informal (social trust and networks) institutions.

The choice of the diagnostic variables of the innovativeness (INN) latent variable was conducted on the basis of the Schumpeterian trilogy (Ciborowski et al., 2019, pp. 138–139). The first phase of the innovation process is invention, which requires certain technological input: financial (INN_1 – gross domestic expenditure in the enterprise sector in euro per inhabitant) and human (INN_2 – R&D personnel as % of the labour force). The invention stage also requires innovative enterprises (INN_3). Technology input is transformed into output reflected by: the higher number of patent applications to the EPO per million inhabitants (INN_4), higher gross value added in professional, scientific and technical activities as % of GDP (INN_5), and greater turnover of innovative companies (INN_6). The final stage of the innovation process is diffusion (imitation). The efficiency of that phase manifests in increased high-tech product export (INN_7).

The diagram applied in the PLS-SEM model described in this article is presented in Figure 1. The estimation will be conducted using SmartPLS 3.0 software (Ringle et al., n.d.).

Figure 1. Diagram of the PLS-SEM model used in the study



Source: author's work.

4. Modelling results and discussion

Table 3 presents the sub-model measurement estimates and statistical verification measures. The signs of factor loadings are consistent with the initial expectations and the economic theory, which means that the sub-model is coincident. All the factor loading values are above 0.400 and are statistically significant at the level of $p < 1\%$. INST and INN latent variables on average extract more than 50% of the variance. The sub-model can be positively verified in terms of convergent validity. The accuracy of the choice of indicators for latent constructs is indicated by the high values of the internal consistency reliability measures – both Cronbach's alpha and the composite reliability take values between 0.600 and 0.950. The discriminant validity of the sub-model is evidenced by the HTMT measure (equal to 0.889; 95% CI from 0.812 to 0.987) and its 95% confidence interval (that does not include 1.000). Moreover, the results of CTA-PLS indicate that 95% of the tetrad values were insignificant ($p > 1\%$; 5,000 samples in a bootstrapping procedure), which means that latent constructs were defined properly. In conclusion, the estimated measurement sub-model has been positively verified in terms of substantive and statistical criteria.

Table 3. Estimates of the measurement (outer) model

Indicator	Convergent validity			Internal consistency reliability	
	factor loading values	*p*-value	AVE	Cb-α	pc
INST latent variable					
$INST_1$	0.797	0.000	0.659	0.924	0.938
$INST_2$	0.913				
$INST_3$	0.816				
$INST_4$	0.814				
$INST_5$	0.785				
$INST_6$	0.839				
$INST_7$	0.900				
$INST_8$	0.588				
INN latent variable					
INN_1	0.916	0.000	0.586	0.877	0.906
INN_2	0.897				
INN_3	0.787				
INN_4	0.878				
INN_5	0.618				
INN_6	0.574				
INN_7	0.599				

Note. 5,000 samples in bootstrapping procedure.
Source: author's work based on the modelling results.

The INST latent variable, which refers to the quality of institutions, is most strongly correlated with $INST_2$ (0.913), i.e. the integrity of the legal system measure. The values of the latent variable are also very strongly reflected by $INST_7$ (0.900), i.e. the synthetic indicator of organisational trust. The correlation of the INST variable with: $INST_6$ (0.839; interpersonal trust), $INST_3$ (0.816; property rights), $INST_4$ (0.814; business regulations), $INST_1$ (0.797; rule of law) and $INST_5$ (0.785; business freedom) successively is strong. The social network synthetic measure ($INST_8$) has the lowest factor loading value (0.588), indicating that changes of the INST construct are reflected by this indicator in a moderate way.

The innovativeness (INN) construct is most strongly reflected by INN_1 (0.916), i.e. gross domestic expenditure in the business enterprise sector (euro per inhabitant). Three indicators are strongly correlated with the INN latent variable, and these are as follows: INN_2 (0.897; R&D personnel as a % of the labour force), INN_4 (0.878; patent applications to the EPO per million inhabitants) and INN_3 (0.787; innovative enterprises as a % of the total number of enterprises). The changes of the INN variables are reflected by the changes of INN_5 (0.618; gross value added in professional, scientific and technical activities as a % of GDP), INN_7 (0.599; high-tech export in euro per inhabitant) and INN_6 (0.574; total turnover of innovative enterprises as a % of GDP) in a moderate way.

Formula (2) presents the estimation of the structural sub-model, which is in the form of a single stochastic equation (significance at the $p < 0.001$ level):

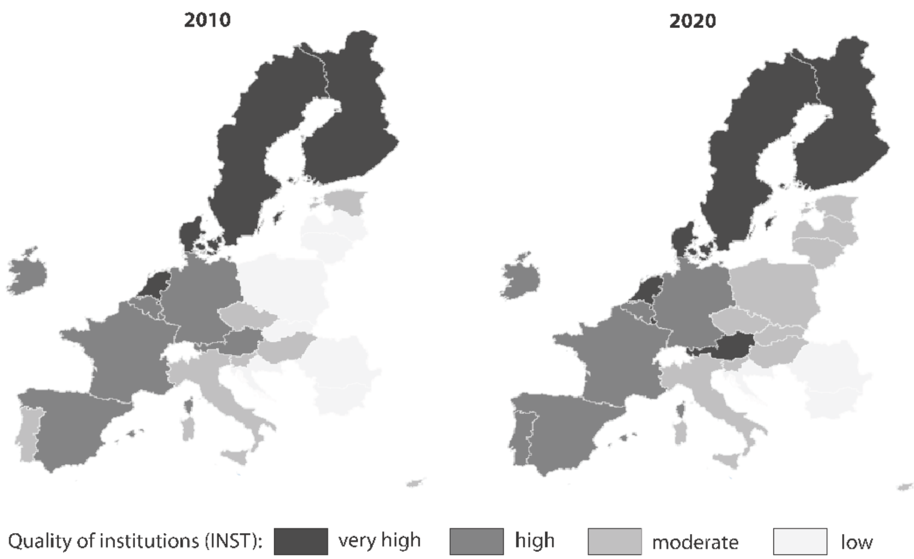
$$\begin{gathered} \widehat{\mathrm{INN}}_{2010\,\&\,2020} = 0.847^{***} \cdot \mathrm{INST}_{2010\,\&\,2020} - 3.939 \\ R^2 = 0.717 \qquad \text{S-G} = 0.398. \end{gathered} \tag{2}$$

On average, in 2010 and 2020, the quality of institutions (the INN latent variable) had a strong and positive (0.847) statistical relationship with the level of innovativeness (INN latent variable). The relationship between variables is considered to be statistically significant, as is the $p < 1\%$ level. The variation of the INN latent variable is explained in approximately 72% by the variation of the INST latent construct. The degree of the structural model fit is considered satisfactory. The value obtained through S-G test indicates that the model has a good predictive power. The general value of the S-G test for the endogenous INN variable is equal to 0.398 (10 blindfolds), and greater than 0.000. The structural model has therefore been proven to be positively verified.

As the PLS-SEM model applied in this article may be considered to be positively substantively and statistically verified, the values of latent variables can be used for the linear ordering of EU countries in terms of the level of unobservable categories.

Figures 2 and 3 present the division of EU economies in terms of the quality of institutions (INST latent variable) and the level of innovativeness (INN latent variable) in 2010 and 2020.

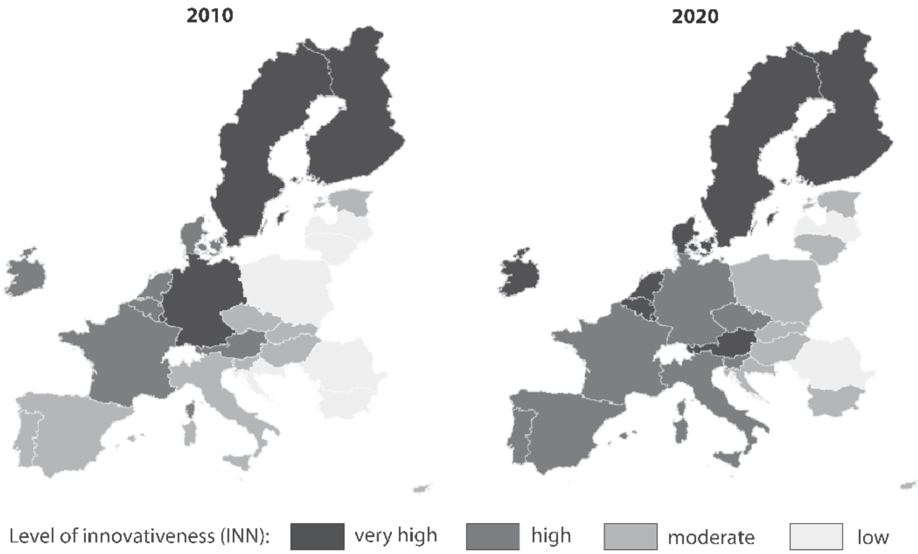
Figure 2. Typological groups of the quality of institutions in EU countries



Source: author's work based on modelling results.

In 2010, four economies were classified as countries with a very high quality of institutions: Denmark, Finland, the Netherlands and Sweden. In 2020, this group also included Austria and Luxembourg. High-quality institutions were observed in 2010 in seven EU member states: Austria, Belgium, France, Germany, Ireland, Luxembourg and Spain) and in 2020 this group included: Belgium, France, Germany, Ireland, Malta, Portugal and Spain. The third typological group was most numerous both in 2010 (Cyprus, the Czech Republic, Estonia, Hungary, Italy, Malta, Portugal and Slovenia) and 2020 (Cyprus, the Czech Republic, Estonia, Hungary, Italy, Latvia, Lithuania, Poland, the Slovak Republic and Slovenia). In 2010, seven countries were characterised by a low quality of institutions: Bulgaria, Croatia, Latvia, Lithuania, Poland, Romania and the Slovak Republic. In 2020, only three economies belonged to that group: Bulgaria, Croatia, and Romania.

Figure 3. Typological groups of the level of innovativeness of EU countries

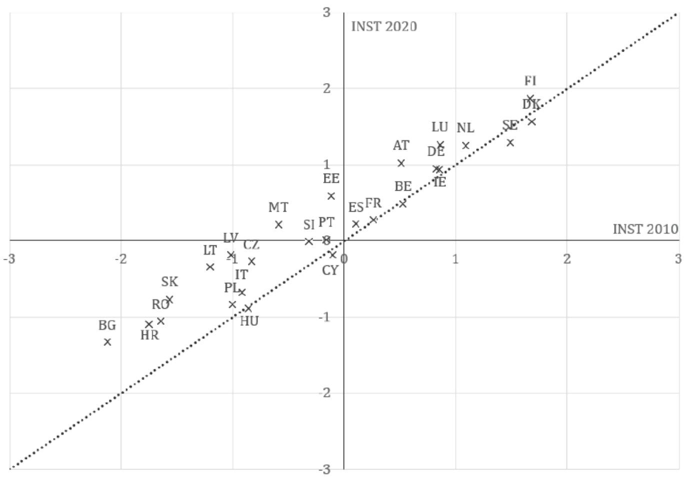


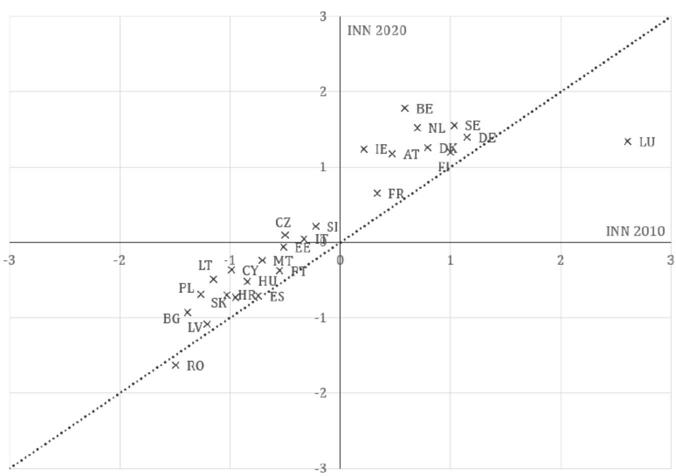
Source: author's work based on modelling results.

In terms of innovativeness, only four countries achieved its very high level in 2010: Finland, Germany, Luxembourg and Sweden. In 2020, this group included eight EU economies: Austria, Belgium, Denmark, Finland, Germany, Luxembourg, the Netherlands and Sweden. The group of countries considered to have a high level of innovativeness in 2010 was formed by: Austria, Belgium, Denmark, France, Ireland and the Netherlands, whereas by: the Czech Republic, France, Germany, Italy, Portugal, Slovenia and Spain in 2020. A moderate level of innovativeness was established in ten economies: Cyprus, the Czech Republic, Estonia, Hungary, Italy, Malta, Portugal, the Slovak Republic, Slovenia and Spain in 2010 and nine countries in 2020: Bulgaria, Croatia, Cyprus, Estonia, Hungary, Lithuania, Malta, Poland and the Slovak Republic. A low level of innovativeness was reported in 2010 in: Bulgaria, Croatia, Latvia, Lithuania, Poland and Romania and in 2020 in Latvia and Romania. A noticeably worse innovation performance was achieved by post-communist EU countries.

Figure 4 presents a comparative analysis of the changes in the values of the latent variables in the PLS-SEM model defining the quality of institutions (INST) and the level of innovativeness (INN). It can be concluded that the values of both analysed latent constructs increased over time in most EU economies. This indicates a gradual growth in the quality of institutions and the level of innovation over the years among EU member states. Only a few of them achieved lower scores in INST and INN values in 2020 compared to 2010. In 2020, compared to 2010, a lower quality of institutions was recorded only in five EU economies: Belgium, Cyprus, Denmark, Hungary and Sweden. A lower level of innovativeness in 2020, compared to 2010, was reported only in two EU countries: Luxembourg and Romania.

Figure 4. Changes in the values of latent variables (INST and INN) over time (2010–2020)





Note. AT – Austria, BE – Belgium, BG – Bulgaria, CY – Cyprus, CZ – the Czech Republic, DE – Germany, DK – Denmark, EE – Estonia, ES – Spain, FI – Finland, FR – France, HR – Croatia, HU – Hungary, IE – Ireland, IT – Italy, LT – Lithuania, LU – Luxembourg, LV – Latvia, MT – Malta, NL – the Netherlands, PL – Poland, PT – Portugal, RO – Romania, SE – Sweden, SI – Slovenia, SK – the Slovak Republic.
Source: author's work based on modelling results.

The final ranking of EU countries in terms of the quality of institutions and the level of innovativeness in 2010 and 2020 are presented in Table 4. In 2010, the highest quality of institutions was observed in Denmark and the lowest in Bulgaria. The highest level of innovativeness in 2010 was observed in Luxembourg, while the lowest in Romania. Finland led the classification in terms of the INST latent variable in 2020, while Bulgaria closed the ranking. Belgium was characterised by the highest level of innovativeness in 2020 and the lowest level was reported in Romania.

Table 4. Ranking of EU countries according to the values of latent variables (INST and INN)

Country	2010		2020		Change in the ranking	
	INST	INN	INST	INN	INST	INN
Austria	9	8	6	9	+3	–1
Belgium	8	7	10	1	–2	+2
Bulgaria	26	25	26	24	=	+1
Croatia	25	21	25	21	=	=
Cyprus	12	20	16	16	–4	+4
Czech Republic	17	13	18	12	–1	+1
Denmark	1	5	2	6	–1	–1
Estonia	13	14	9	14	+4	=
Finland	2	4	1	8	+1	–4
France	10	9	11	10	–1	–1
Germany	7	2	7	4	=	–2
Hungary	18	18	23	19	–5	–1
Ireland	6	10	8	7	–2	+3
Italy	19	12	20	13	–1	–1
Latvia	21	23	17	25	+4	–2
Lithuania	22	22	19	18	+3	+4
Luxembourg	5	1	4	5	+1	–4
Malta	16	16	13	15	+3	+1
Netherlands	4	6	5	3	–1	+3
Poland	20	24	22	20	–2	+4
Portugal	14	15	14	17	=	–2
Romania	24	26	24	26	=	=
Slovak Republic	23	19	21	23	+2	–4
Slovenia	15	11	15	11	=	=
Spain	11	17	12	22	–1	–5
Sweden	3	3	3	2	=	+1

Note. = denotes no changes in the ranking.

Source: author's work based on modelling results.

The innovativeness ranking based on the INN latent variable was compared to the two most popular innovativeness indexes, i.e. the Summary Innovation Index (SII) developed by the European Commission (2011, 2022) and the Global Innovation Index (GII) created by Cornell University, the World Intellectual Property Organization (WIPO) and the INSEAD (Fr. Institut Européen d'Administration des Affaires) Business School (INSEAD, 2010; Cornell University, INSEAD & WIPO, 2020). The results of the correlation analysis indicate that the INN latent variable is very strongly corelated with the synthetic measure developed by the European Commission and the one created by INSEAD, WIPO and Cornell University (Tables 5 and 6). The conducted analysis implies that the constructed synthetic measure (INN latent variable) is a valid indicator of the innovativeness of EU countries.

Table 5. Comparison of the INN latent variable to synthetic measures of innovativeness of EU economies, 2010 – Rho Spearman correlation

Specification	INN_{2010}	SII_{2010}	$GII_{2009/2010}$
INN_{2010}	1.000	0.917	0.936
SII_{2010}	0.917	1.000	0.924
$GII_{2009/2010}$	0.936	0.924	1.000

Source: author's work based on modelling results.

Table 6. Comparison of the INN latent variable to synthetic measures of innovativeness of EU economies, 2020 – Rho Spearman correlation

Specification	INN_{2020}	SII_{2020}	GII_{2020}
INN_{2020}	1.000	0.931	0.891
SII_{2020}	0.931	1.000	0.923
GII_{2020}	0.891	0.923	1.000

Source: author's work based on modelling results.

There are not many macroeconomic empirical studies described in the literature on this subject, although as Wang (2013, p. 130) notes: 'empirical studies on this matter have been largely lacking but not non-existent'.[4] The modelling results presented in this paper seem to be in line with other researchers' findings. For example, Varsakelis (2006) on the basis of empirical studies of 29 countries in 1995–2000 noted that the quality of formal institutions positively influences the level of innovativeness, i.e. the growing quality of state institutions may lead to an increase in innovative productivity. Alexander (2012) also proved the importance of formal institutions (regulatory ones) in innovation processes in the economy. Tebaldi and Elmsile (2013) found that institutions positively contribute to explaining much of the cross-country variation in patent count across world economies. They also concluded that the institutional factor of innovativeness is equally important in innovator and imitator countries. Finally, Wang (2013) provided evidence that both formal and informal institutions have a strong direct impact on innovativeness (R&D inputs and outputs). Lee and Law (2016), and Khan et al. (2017) also concluded that both formal (measured by the International Country Risk Guide index) and informal (approximated by social capital measures) institutions have a strong positive impact on

[4] In most cases, the study of the relationship between institutions and innovation involves an analysis of the importance of organisations in the innovation process, rather than social norms.

innovative activity in contemporary world economies. Moreover, Boudreaux (2017) also provided empirical evidence that institutions matter in innovativeness, concluding that the legal system plays the most important role in innovation inputs, while freedom of trade – in innovation outputs. Research conducted by Sharma et al. (2022), concerning 50 world economies during the period from 1997 to 2017, indicated that institutional quality plays an important part in dynamizing innovation activities, especially in developed countries. Furthermore, Blanco and Goel (2023) established, using a large sample of nations over 2018–2020, that different institutional aspects (regulatory quality, corruption, government size, patent protection and state fragility) impact innovation efficiency differently, both in OECD and non-OECD economies.

5. Conclusions

The aim of the study was to measure the quality of institutions and the level of innovativeness of EU economies, and to identify the relationship between these categories. The article generalised a panel PLS-SEM model for 2010 and 2020. On the basis of the conducted econometric analysis, it can be concluded that the quality of institutions is positively, strongly and statistically significantly (p < 1%) correlated (0.847) with the level of innovativeness of EU economies in the researched years. Based on the theoretical analysis, the conducted exploratory PLS-SEM modelling and the analysis of other authors' empirical results, it can be assumed that not only may the relationship between institutions and innovativeness be correlational, but also causal. Countries with quality institutions also exhibited higher levels of innovativeness. The constructed innovation rankings turned out to be very similar to the rankings compiled under the European Innovation Scoreboard and Global Innovation Index. This indicates that the obtained results are valid.

Due to the lack of sufficient statistical data, the measurement of institutions' quality was incomplete, which altogether proved to be the most serious limitation of the performed analysis. Institutions as such are not easy to measure since there are not many indicators related to their quality. This remark particularly concerns informal institutions that are codified only in the perception of the society (see: Voigt, 2018). Other limitations of the research result from the short period that the research covered and small population size. However, it should be noted that the proposed panel generalisation of PLS-SEM models reduced the effect of the negative estimation of the small population size on the results.

Multiple regression has historically been the method of choice for this type of research. The application of PLS-SEM, which is an extension of the traditional multiple regression method of analysing structural relationships, will expand the ability to construct much more complex statistical models. The advantage of PLS-SEM over traditional modelling is the possibility of using a latent dependent variable (Y side of the model is usually limited to one diagnostic variable) in the model. Moreover, PLS-SEM is well-suited for macroeconomic data-based modelling due to the less restrictive verification criteria compared to traditional modelling techniques.

There is no doubt that the innovativeness of contemporary economies and the factors that determine it are very important and topical categories nowadays. Future research will focus on determining the causal relationship between institutions and innovativeness, including moderating effects, checking endogeneity and common method variance (see: Spector, 2019). As He and Tian (2020, p. 394) note: 'clever identification strategies need to be designed to establish causal links between institutions and innovation'.

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