UDK [001.89+004]:330.3
JEL Classification: O32, M21
DOI: https://doi.org/10.54929/2786-5738-2024-16-11-01

MODELING THE IMPACT OF INNOVATION ON BUSINESS

МОДЕЛЮВАННЯ ВПЛИВУ ІННОВАЦІЙ НА БІЗНЕС

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The article is devoted to analysis of the impact of innovations on business in the context of digitalization and automation of business processes. The study purpose is to model the impact of innovation development (estimated as number of patent applications in the field of digital technologies) on business development (as GNI). To achieve the goal, the following tasks are performed: forming a sample of countries and database according to selected indicators, data normalization, regression analysis, spline modelling, checking significance of constructed models, comparing and choosing the most optimal one. The formed sample is based on data from the World Bank and European Patent Office for 92 world countries regarding the values of GNI and number of patent applications in the field of digital technologies. Within the framework of regression analysis, pairwise regression and polynomial regression models are built using the Statgraphics 19 software. MAR Spline modelling is carried out using Salford Predictive Modeler 8.0 software. To check statistical significance, criteria of Durbin-Watson, Student, Fisher, etc. are used. The study results demonstrate the importance of innovation activity for business development and economic growth, which is confirmed by simulated and estimated positive complex relationship. The high value of the coefficient of determination in linear regression model demonstrates a strong dependence and significant impact of patent applications on GNI. The fifth-order polynomial regression more adequately describes complex relationships between variables. The quality of the forecast calculated using spline model is confirmed by the value of mean absolute error, which is close

to zero. The forecast values are increased to the 5th degree. Accordingly, increasing the opportunities for filing and obtaining patents will contribute to greater GNI growth. The obtained results can be useful for government and business structures, public organizations, educational and scientific institutions, and are the basis for further research.
Key words: *business; digital technologies; economic growth; GNI; innovation; patent applications.*

Стаття присвячена аналізу впливу інновацій на бізнес в умовах цифровізації та автоматизації бізнес-процесів. Метою дослідження є моделювання впливу розвитку інновацій (оцінюється як кількість патентних заявок у сфері цифрових технологій) на розвиток бізнесу (як валовий національний дохід). Для досягнення мети здійснюється ряд завдань: формування вибірки країн і бази даних за обраними індикаторами, нормалізація даних, регресійний аналіз, сплайн-моделювання, перевірка статистичної значущості побудованих моделей, їх порівняння та обрання найбільш оптимальної. Сформована вибірка базується на даних Світового банку та Європейського патентного відомства для 92 країн світу щодо величин валового національного доходу та кількості патентних заявок у сфері цифрових технологій. Узагальнені дані нормалізуються за допомогою модифікованої логістичної функції. У межах регресійного аналізу будуються моделі парної регресії та поліноміальної регресії з використанням програмного забезпечення Statgraphics 19. Моделювання MAR Spline здійснюється за допомогою програмного забезпечення Salford Predictive Modeler 8.0. Для перевірки статистичної значущості використовуються статистичні критерії Дарбіна-Ватсона, Стьюдента, Фішера та ін. Результати дослідження засвідчують важливість інноваційної діяльності для бізнес-розвитку та економічного зростання, що підтверджується змодельованим і оціненим позитивним складним зв'язком. Високе значення коефіцієнта детермінації у моделі лінійної регресії демонструє сильну залежність та значний вплив патентних заявок на валовий національний дохід. Поліноміальна регресія п'ятого порядку адекватніше описує складні зв'язки між змінними. Якість прогнозу, розрахованого за сплайновою моделлю, підтверджено значенням середньої абсолютної похибки, яке наближене до нуля. Прогнозні значення підвищені до 5 ступеня. Відповідно збільшення можливостей для подачі та отримання патентів сприятиме більшому зростанню ВНД. Результати проведеного дослідження можуть бути корисними для широкого кола стейкхолдерів (урядові та бізнес структури, громадські організації, освітні та наукові установи) та є основою для подальших наукових досліджень у цій сфері.
Ключові слова: *бізнес; цифрові технології; економічне зростання; ВНД; інновації; патентні заявки.*

INTRODUCTION

In today's world, where technological progress is rapidly changing the conditions for entrepreneurship, research into the impact of innovation on business is becoming increasingly relevant. Innovations, including both new technologies and new approaches to organizing business processes, can radically change the competitive situation in the market, because they offer unique solutions for consumers. In the context of digitalization of the economy, companies that implement innovative solutions have significant advantages, because they respond faster to changes in demand, optimize costs, improve product quality and ensure sustainable development. That is why this topic is relevant and requires detailed scientific research. Moreover, the issue of developing innovative business is becoming particularly relevant given the needs of post-war reconstruction in Ukraine. The introduction of innovative business models and new technologies can be the key to restoring the economy and improving the quality of life of citizens. Therefore, studying the impact of innovation on business is also an important step towards creating a sustainable and competitive economy.

LITERATURE REVIEW

The different links and causal relationships between innovation and business development are popular research objectives in modern economic science [1]. A large number of scholars highlight the role of innovative information technologies in shaping the flexibility of companies. Sambamurthy et al. [2] emphasize that innovative information technologies can not only ensure effective management of business processes, but also become critical tools for shaping strategic flexibility. It is also noted that the introduction of information technologies changes traditional business models, promotes the development of innovations and increases the efficiency of entrepreneurial activity. Xakimova et al. [3] emphasize that the use of business intelligence systems is becoming a critical success factor for modern companies that want to increase their competitiveness in the global market. Kuzior et al. [4] studied the opportunities of using artificial intelligence in the context of management of open innovation. Lavanya et al. [5] talk about the importance of using corporate applications, they emphasize that corporate programs, such as enterprise resource management systems (ERP) and customer relationship management (CRM), enable companies to optimize their internal processes and improve the level of customer service. Lee & Kim [6] consider the characteristics of the quality of Big Data analytics that affect business efficiency. Artyukhov et al. [7, 8] studied the process of innovation transfer within the framework of an entrepreneurial university, under the conditions of interaction between education and business and the open innovation model. At the same time, the issue of modelling the impact of innovations on business remains urgent, given the multifaceted nature of this research area, the insufficient number of studies focused on quantitative impact and empirical confirmation, various indicators and metrics that are used as the basis for modelling.

AIMS AND OBJECTIVES

Research aim is to model the impact of innovation development (estimated as the number of patent applications in the field of digital technologies) on business development (as gross national income). To achieve the goal, regression analysis, spline modelling, and verification of the statistical significance of the models are necessary objectives.

METHODOLOGY AND RESEARCH METHODS

A regression analysis (pairwise regression and polynomial regression using Statgraphics 19 software) and MAR Spline modelling using Salford Predictive Modeler software was performed. Durbin-Watson statistic, Student, Fisher and other criteria are used for checking statistical significance. The information base of the study was the data for 92 world countries from the World bank and European Patent Office (EPO), in particular the value of gross national income (GNI) [9], as one of the key indicators reflecting the general level of economic activity of countries and, accordingly, the state of business development. As an indicator for assessing innovation development in this study the number of patents filed in the field of digital technologies was selected [10], which well demonstrates the connection of innovation and business. The data for the study were taken nominal, but in different units of measurement, so their distribution laws deviate from normal. Thus, the data were previously normalized using a modified logistic function to convert to a dimensionless scale from 0 to 1.

DATA ANALYSIS AND RESULTS

To provide a detailed analysis of the impact of science and technology on business, regression analysis was conducted using Salford Predictive Modeler software, and one of its key components is the MARS method. It allows to model nonlinear relationships between multiple variables and identify complex patterns in the data. The developed model for assessing the impact of patent applications number in the field of digital technologies on GNI is presented in Table 1.

Table 1

The model for assessing the impact of number of patent applications on GNI (pairwise regression)

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0,110636	0,0224542	4,92718	0,0000
Patent applications (digital communications)	0,784207	0,0426353	18,3934	0,0000

Source: built by the authors

The linear regression is statistically significant according to the Student's t-test and the significance level (p-value). The coefficient of determination explains 79% of the variation in GNI ($R^2 = 0.79$), which indicates a strong relationship between the number of filed patents and GNI (close positive / direct relationship). The coefficient for the variable «Patent applications» is statistically significant (p-value < 0.001), which indicates a high level of confidence in the results obtained. This means that with an increase in the number of patent applications, GNI increases, which is consistent with theoretical ideas about the impact of innovative activity on economic development. And since the P-value in the table is less than 0.05, there is a statistically significant relationship between the variables at a confidence level of 95.0%. Small values of the standard error of the estimate (0.0304786) and the mean absolute error (0.0156047) are indicators of high accuracy of the model. The value of the Fisher F-test ≈ 338.32 has a significance level a(F) ≈ 0 < 0.05 confirms the statistical significance of the R2 value, i.e. the equation is statistically significant overall at a = 0.05.

The importance of innovation activity for economic growth is also confirmed by the equation of the regression model (1), which demonstrates the existence of a strong positive relationship between the number of patent applications and gross national income:

$$GNI = 0{,}110636 + 0{,}784207 \times \text{Patent applications} \quad (1)$$

It should be noted that the relationship between patent applications related to information technologies and the level of GNI has a complex nonlinear nature, which is due to the influence of both internal factors related to the characteristics of each country, which it puts forward for the innovator in order to certify the invention, and various external factors directly related to the procedure for developing the invention (technological, socio-economic, educational and various others, specific to each invention). Therefore, it is advisable to develop nonlinear regression models, check their significance and compare the results with the developed linear regression (1). As such models, it is proposed to use polynomial regressions of order m and model a multivariate adaptive regression spline, the algorithm of which uses data mining and allows you to identify complex nonlinear dependencies between factor and predictor variables.

Thus, a comparison of polynomial regressions (Table 2) developed using Statgraphics 19 software showed that the best polynomial regression is the 5th order according to Fisher's exact test (F-Ratio = 170,18; P-Value = 0,0000), Student's test and significance level. For the 6th order model, the relationship between patent applications and GNI becomes linear.

Table 2

The model for assessing the impact of number of patent applications on GNI (polynomial regression)

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	53,9179	40,6735	1,32563	0,1885
Patent applications (digital)	-445,746	300,423	-1,48373	0,1415
Patent applications (digital)^2	1449,34	875,064	1,65626	0,1013
Patent applications (digital)^3	-2297,81	1256,62	-1,82857	0,0709
Patent applications (digital)^4	1778,48	890,114	1,99803	0,0489
Patent applications (digital)^5	-537,708	249,001	-2,15947	0,0336

Source: built by the authors

The statistically significant 5th order polynomial regression is given by the formula:

$$\begin{aligned}GNI = {} & 53{,}92 - 445{,}75 \text{ x Pattent applications} \\ & + 1449{,}34 \text{ x Pattent applications}^2 \\ & - 2297{,}81 \text{ x Pattent applications}^3 \\ & + 1778{,}48 \text{ x Pattent applications}^4 \\ & - 537{,}708 \text{ x Pattent applications}^5\end{aligned} \tag{2}$$

Statistical criteria confirm the significance of polynomial regression (2) and its higher quality compared to linear regression (1). The coefficient of determination is 90.2808% and the adjusted coefficient of determination is 90.2871%, meaning that the model explains more than 90% of the variability in GNI, which is a very high figure. The high explanatory power of the model indicates its adequacy for describing the complex nonlinear relationships between innovation activity and economic development. The Durbin-Watson statistic (1,75293 (p-value=0,1109)) tests the residuals to determine whether there is a significant correlation based on the order in which they appear in the model (2). Since the P-value is greater than 0.05, there is no evidence of consistent autocorrelation in the residuals at the 95% confidence level.

The curve in the graph (Fig. 1), representing the 5th order polynomial model, has a complex curvilinear character, which indicates the presence of a nonlinear relationship between GNI and patent applications.

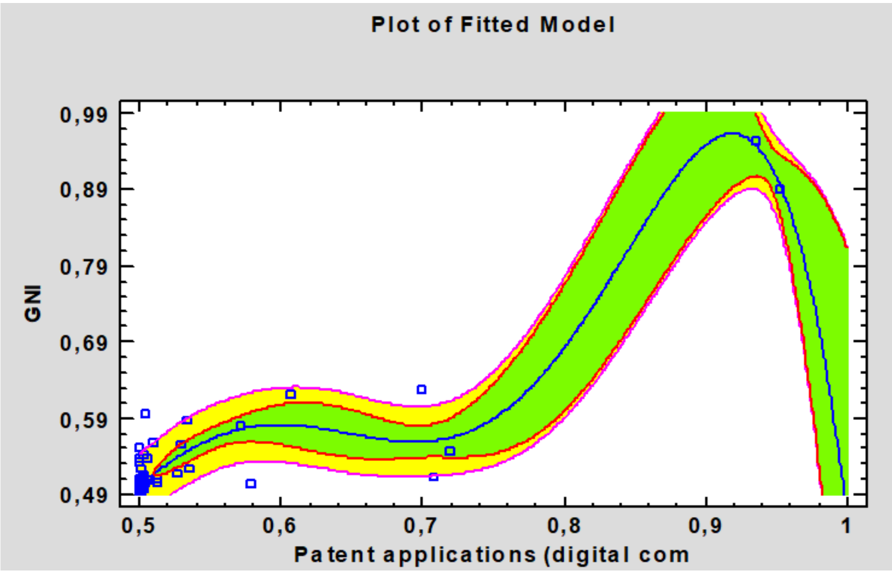

Fig. 1. Polynomial regression graph

Source: built by the authors

Such a nonlinear relationship is quite expected, since the relationship between economic development (GNI) and innovative activity (patent applications) usually has a complex, nonlinear nature. An increase in the number of patent applications at a certain stage may be accompanied by an increase in GNI, but later this relationship may become more complex, for example, reaching a plateau or even showing a downward trend.

The next step, in order to comprehensively analyse the impact of the number of patent applications received in the country, related to the processes of digitalization, and the level of GNI, a flexible tool of non-parametric regression modelling was used – spline multivariate adaptive regression. Its development begins with the definition of the so-called «basic mirror functions», which are simple linear functions that are combined to create more complex models. The algorithm starts with a simple model and gradually adds or removes basic functions to improve the fit, using two procedures – forward and backward stepwise selection – that do not satisfy the test criterion [11] and the Generalized Cross Validation criterion (GCV), which allows determining both the accuracy of predictions and the complexity of the model [12], the closer its value is to zero, the better the quality of the model. Also, to assess the quality of the developed spline using a certain set of basic functions, the values of the mean absolute error (MAE), the mean absolute deviation (MAD) are checked.

For the development of the multivariate adaptive regression spline Salford Predictive Modeler 8.0 software was applied (Fig. 2).

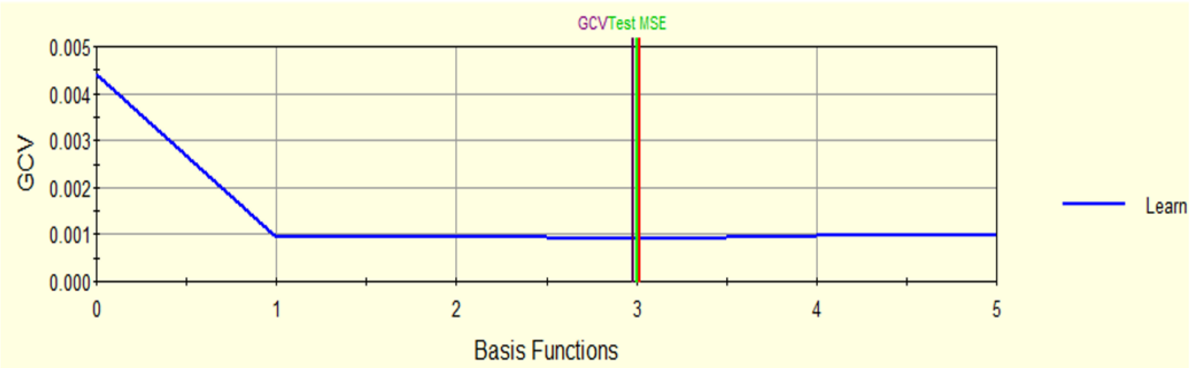

Fig. 2. MARS model graph

Source: built by the authors

The graph (Fig. 2) clearly demonstrates the dynamics of changes in GCV values depending on the number of basic functions. There is a trend, a sharp decrease in the GCV value when the number of basic functions increases to 3, after which the curve stabilizes, and further addition of functions practically does not affect the criterion. This dependence allows us to conclude that the optimal number of basic functions is 3. It is this configuration that provides the best balance between the complexity of the model and its predictive ability, as evidenced by the minimum GCV value.

The resulting basis functions are as follows:

$$BF1 = \max(0, PATENT\_APPLICATIONS - 0.572159) \quad (3)$$
$$BF2 = \max(0, 0.572159 - PATENT\_APPLICATIONS) \quad (4)$$
$$BF3 = \max(0, PATENT\_APPLICATIONS - 0.505612) \quad (5)$$

Thus, the MARS model was built to forecast gross national income based on three basic functions (BF1, BF2, BF3), which are expressed as mathematical equations describing the nonlinear relationships between patent applications and GNI. The BF1 function models the positive impact of an increase in the number of patent applications above 0.572159 on GNI growth, BF2, on the contrary, is activated when the number of patent applications is less than 0.572159, and BF3 models the additional negative impact of a decrease in patent applications below 0.505612.

The final equation of the model combines the three basic functions and the corresponding coefficients to obtain a GNI forecast. It is given by formula:

$$GNI = 1{,}03658 + 8{,}91725 \times BF1 - 7{,}42895 \times BF2 - 7{,}92616 \times BF3 \quad (6)$$

Table 3 shows statistical characteristics of the optimal MARS model.

A comparative analysis of the forecasts obtained based on the results of the developed polynomial regression (2) and the multivariate adaptive regression spline (6) is given in Table 4.

The quality of the calculated forecast using the MARS model (6) is the mean absolute error (MAE) value, which is 0.014249, the closer this value is to zero, the better the forecast value. If we analyze the difference between the calculated forecast values using the polynomial model (2) and the real normalized GNI values, we see that these differences are significant, and the MAE is far from zero. But the statistical test of the developed model revealed its statistical significance. The forecast values are increased to the 5th degree, respectively, the more opportunities there are for submitting and receiving patents from the state, the more GNI will grow.

This study has certain limitations regarding the sample of countries and the indicators selected for study, which can be expanded in future studies. In addition to the field of digital technologies, other areas can be studied in terms of the number of patent applications, as well as other indicators that characterize business development and economic growth in general. Also, a similar analysis can be carried out at different points in time in dynamics.

Table 3

Statistical characteristics of the optimal MARS model

Statistical characteristic	Result
RMSE	0.02696
MSE	0.00073
GCV	0.00092
MAD	0.01425
MAPE	0.02593
SSY	0.39774
SSE	0.06689
R-Sq	0.83182
R-Sq Norm	0.83182
GCV R-Sq	0.79288
MSE Adjusted	0.00070
R-Sq Adjusted	0.82609

Notes: RMSE – Root Mean Square Deviation, MSE – Mean Squared Error, GCV – Generalized Cross-Validation; MAD – Mean absolute deviation; MAPE – Mean absolute percentage error; SSY, SSE – statistical characteristics of analysis of variance that are taken into account when checking the quality of splines

Source: calculated by the authors

Table 4

Comparative analysis of the forecasts based on the results of polynomial regression and the multivariate adaptive regression spline

Country	GNI-norm	GNI_polinom	GNI_MARS	Abs (delta)
1	2	3	4	5
Albania	0,495262	2118,844	0,500514397	0,005252
Argentina	0,511082	2118,844	0,500514397	0,010567
Armenia	0,495251	2118,844	0,500514397	0,005263
Australia	0,541819	2125,405	0,513681051	0,028138
Austria	0,508803	2136,312	0,535624576	0,026822
Azerbaijan	0,496576	2118,844	0,500514397	0,003939
The Bahamas	0,49505	2118,844	0,500514397	0,005465
Bahrain	0,495859	2118,844	0,500514397	0,004655
Bangladesh	0,50855	2118,844	0,500514397	0,008036
Belarus	0,496685	2118,844	0,500514397	0,003829
Belgium	0,512782	2128,681	0,520264275	0,007482
Belize	0,494762	2118,844	0,500514397	0,005752
Bolivia	0,495933	2118,844	0,500514397	0,004581
Bosnia and Herzegovina	0,495415	2118,844	0,500514397	0,005099
Brazil	0,549626	2118,844	0,500514397	0,049112
Bulgaria	0,49729	2118,844	0,500514397	0,003225
Burkina Faso	0,495232	2118,844	0,500514397	0,005282
Burundi	0,494764	2118,844	0,500514397	0,00575
Canada	0,55519	2224,27	0,530618631	0,024571
Chile	0,503403	2118,844	0,500514397	0,002888
China	0,89108	3173,797	0,886143459	0,004937
Colombia	0,504723	2118,844	0,500514397	0,004209
Costa Rica	0,496707	2118,844	0,500514397	0,003808
Cyprus	0,495487	2123,219	0,509292187	0,013805
Czech Republic	0,502959	2118,844	0,500514397	0,002445
Denmark	0,506931	2133,044	0,529041706	0,02211
El Salvador	0,495559	2118,844	0,500514397	0,004956
Estonia	0,495724	2119,938	0,502708848	0,006985
Fiji	0,494826	2118,844	0,500514397	0,005689

Table 4 continued

1	2	3	4	5
Finland	0,503051	2393,45	0,514555458	0,011504
France	0,580267	2374,974	0,509117909	0,071149
Georgia	0,495385	2118,844	0,500514397	0,00513
Germany	0,620314	2487,028	0,542833133	0,077481
Greece	0,501249	2119,938	0,502708848	0,00146
Guatemala	0,497436	2118,844	0,500514397	0,003079
Guinea	0,49522	2118,844	0,500514397	0,005294
Guyana	0,495145	2118,844	0,500514397	0,00537
Hungary	0,500017	2122,126	0,507097745	0,007081
Iceland	0,495562	2118,844	0,500514397	0,004953
India	0,595447	2135,223	0,533430309	0,062017
Indonesia	0,532619	2118,844	0,500514397	0,032105
Ireland	0,50656	2165,575	0,538681878	0,032122
Israel	0,509755	2161,257	0,53926902	0,029514
Italy	0,557462	2154,769	0,540149851	0,017312
Japan	0,628238	2760,319	0,635303963	0,007066
Kazakhstan	0,500795	2118,844	0,500514397	0,000281
South Korea	0,546096	2809,763	0,654381666	0,108285
Kuwait	0,500265	2118,844	0,500514397	0,00025
Latvia	0,49584	2118,844	0,500514397	0,004674
Lithuania	0,496681	2118,844	0,500514397	0,003833
Luxembourg	0,496338	2126,497	0,51587547	0,019537
Madagascar	0,495126	2118,844	0,500514397	0,005388
Malaysia	0,506214	2118,844	0,500514397	0,0057
Mali	0,495242	2118,844	0,500514397	0,005272
Malta	0,495211	2118,844	0,500514397	0,005303
Mauritania	0,494973	2118,844	0,500514397	0,005542
Mexico	0,538257	2118,844	0,500514397	0,037742
Moldova	0,495106	2118,844	0,500514397	0,005409
Mongolia	0,495158	2118,844	0,500514397	0,005356
Mozambique	0,495181	2118,844	0,500514397	0,005333
Nepal	0,495868	2118,844	0,500514397	0,004646
Netherlands	0,525124	2244,237	0,527839321	0,002716
New Zealand	0,501809	2119,938	0,502708848	0,0009
Niger	0,495137	2118,844	0,500514397	0,005377
Nigeria	0,506825	2118,844	0,500514397	0,006311
Norway	0,51056	2128,681	0,520264275	0,009704
Oman	0,497489	2118,844	0,500514397	0,003026
The Philippines	0,508613	2118,844	0,500514397	0,008098
Poland	0,514999	2125,405	0,513681051	0,001318
Portugal	0,502444	2122,126	0,507097745	0,004654
Qatar	0,499983	2118,844	0,500514397	0,000531
Rwanda	0,495068	2118,844	0,500514397	0,005446
Saudi Arabia	0,524425	2121,032	0,504903298	0,019522
Senegal	0,495505	2118,844	0,500514397	0,005009
Slovakia	0,498312	2118,844	0,500514397	0,002202
Slovenia	0,496503	2118,844	0,500514397	0,004012
South Africa	0,506125	2118,844	0,500514397	0,005611
Spain	0,538316	2139,577	0,54220556	0,00389
Sudan	0,496016	2118,844	0,500514397	0,004499
Sweden	0,51292	2782,777	0,643847926	0,130928
Switzerland	0,518322	2213,695	0,53208292	0,013761
Thailand	0,509157	2118,844	0,500514397	0,008642
Türkiye	0,52258	2122,126	0,507097745	0,015482
Uganda	0,49601	2118,844	0,500514397	0,004504
Ukraine	0,499591	2118,844	0,500514397	0,000923

Table 4 continued

1	2	3	4	5
United Arab Emirates	0,508921	2119,938	0,502708848	0,006212
United Kingdom	0,58558	2237,949	0,528716566	0,056864
United States	0,952574	3164,421	0,869823142	0,082751
Uruguay	0,496557	2118,844	0,500514397	0,003958
Uzbekistan	0,497094	2118,844	0,500514397	0,00342
Vietnam	0,506276	2118,844	0,500514397	0,005762
Zimbabwe	0,495496	2118,844	0,500514397	0,005019
			MAE	0,014249

Notes: abs (delta) – the difference between the normalized GNI values and those calculated using the MARS model, taken in absolute value

Source: calculated by the authors

DISCUSSION AND CONCLUSIONS

It is substantiated that one of the key factors for business development is innovation. Regression analysis of the impact of innovative development, determined by the number of filed patents related to digitalization, on business development, estimated by the macro indicator of gross national income, showed a positive and complex relationship. The high value of the coefficient of determination (0.79) in the linear regression model demonstrates a strong dependence and significant impact of patent applications on GNI. Fifth-order polynomial regression, which was used to adequately describe the relationships, indicated more complex relationships between variables. The quality of the forecast calculated by the MARS model is the value of the mean absolute error, which is equal to 0.014249 (the closer this value is to zero, the better the forecast value). The forecast values are increased to the 5th degree, respectively, the more opportunities there are for submitting and receiving patents, the more GNI will grow.

The research was funded by the Ministry of Education and Science of Ukraine based on the results of the project «Cooperation between business, education and science: institutional and economic models of innovation transfer for national security and sustainable development» (No. 0122U000772).

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