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GDP PER CAPITA VS FOREIGN DIRECT INVESTMENT: KEY DRIVERS OF A COUNTRY'S TECHNOLOGICAL LEADERSHIP

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Abstract. This study aims to test the hypothesis that countries with high GDP per capita achieve technological leadership not primarily due to their domestic production capacity but through the inflow of foreign direct investment (FDI). The research covers 21 developed countries across Western Europe, the Americas, Asia, Africa, and Australia, for the period 2011 to 2022. The Bartlett test, Kaiser-Meyer-Olkin (KMO) criterion, and exploratory factor analysis (EFA) were employed to identify the most relevant indicators for the study. A true fixed-effects stochastic frontier model was applied to panel data, based on the Cobb-Douglas production function and the translogarithmic function, to evaluate the determinants of technological development and identify technical efficiency. Fourteen indicators of technological development were used as independent variables, while five key economic indicators were included as adjustment variables. Research and development expenditure served as the dependent variable. Three frontier models were constructed, incorporating adjustment variables such as GDP per capita, FDI net inflows, and FDI net outflows. The findings provide valuable insights for reviewing the key determinants of technological development management in economically advanced countries.

Keywords: innovations, technological development management, economic development management, sustainable management, gross domestic product, foreign direct investments, stochastic frontier model.

JEL Classification: E22, F21, O11, O33.

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1. Introduction

Experts often believe that technologically leading countries have enough internal economic resources for the effective management of technological development, i.e., they do not need additional attraction from foreign direct investment. According to this approach, countries with a high level of GDP per capita have strong internal economic capabilities to ensure high living standards; develop infrastructure; support education, science and innovation; and ensure technological leadership in various fields (information technology, biotechnology, renewable energy sources, modern production, etc.). These countries use the power of science and innovation to support economic growth, improve their citizens' quality of life, and maintain a competitive advantage on a global scale. All this allows economically developed countries to adapt constantly to new technological challenges and create an environment to encourage and support innovation to be resistant to complex global challenges.

Moreover, due to numerous global changes, countries with high economic growth rates have increased obligations to their population in terms of social security, health care support and protection. It can be assumed that countries alone do not have enough economic capacity for domestic aggregate production to maintain technological leadership. Therefore, to ensure the high performance of the management of technological development, they should actively attract foreign direct investments.

According to Organization for Economic Co-operation and Development (2023) statistics, the largest countries receiving foreign direct investment are the USA (USD 109 billion), Brazil (USD 21 billion) and China (USD 21 billion). The top three countries that are the largest providers of foreign direct investment include the USA (USD 110 billion), Germany (USD 57 billion) and China (USD 50 billion).

This study investigates the independent impact of foreign direct investment (FDI) on technological leadership, an area that remains underexplored in the literature. While it is widely acknowledged that high GDP per capita is a characteristic of technological leaders, this research proposes a nuanced view that separates the effects of domestic economic output from those of FDI. This differentiation provides a fresh perspective in economic studies, focusing on how developed countries can leverage foreign investments to bolster technological advancements irrespective of their domestic production capabilities.

On this basis, the following research hypothesis is formed: *countries with high GDP per capita are technological leaders not because of high domestic aggregate production but because of the inflow of foreign direct investments*.

2. Literature review

2.1. Influence of the country's economic well-being on the effectiveness of the management of technological development

Economic well-being, often measured by gross domestic product (GDP), income per capita, and overall quality of life, plays a fundamental role in ensuring the effectiveness of the management of technological development. A strong and stable economy can provide the necessary resources for research and development, education and innovation. Developing countries often face significant challenges due to the lack of capital and technological expertise necessary for the effective management of technological development (Hu et al., 2021; Asafo-Agyei & Kodongo, 2022; Fagbemi & Osinubi, 2020). Foreign direct investment (FDI) can serve as a catalyst by providing additional financial resources and technological capabilities, which may enhance the development processes in these countries (Amendolagine et al., 2023; Tarighi & Shavvalpour, 2021). However, the impact and desirability of technological development facilitated by FDI can vary significantly depending on the unique socioeconomic and political conditions of each country or region (Sultana & Turkina, 2020; Asim & Sorooshian, 2019). For policymakers, finding a balance between the benefits of FDI and concerns regarding economic sovereignty, dependency, and potential negative social and environmental impacts is critical for ensuring sustainable technological growth. The literature review shows that a strong economic foundation can foster a culture of innovation, support entrepreneurship and create incentives for the development of technology-related sectors of the economy.

Adrangi and Kerr (2022), Kharazishvili et al. (2020) propose a many-dimensional concept to study GDP transformation as a multivariate indicator that describes the economic growth and technological development of a country.

The relationship between the development of information and communication technologies and economic growth was studied previously (Awad & Albaity, 2022). Ata and Saltan (2023) analysed the relationship between technological leadership and the degree of information and communication technology use. The research is based on constructing a panel regression model, where the dependent variable is the country's innovative development indicator (the number of issued patents). The independent variables are the number of new enterprises founded in the country during the fiscal year, exports of high-tech goods, GDP per capita, and the number of registered startups. As a result of the analysis, the greatest positive relationship is observed between the level of the country's technological development and the development of information and communication technologies.

Carrasco and Tovar-García (2023), Dementyev and Kwilinski (2020), Dementyev et al. (2021), Szczepańska-Woszczyna and Gatnar (2022) determine the factors that have the most significant influence on the growth of high-tech goods exports in terms of the transfer of innovations for the country's socioeconomic development. The researcher also considers GDP among the factor variables. However, the calculations prove that the characteristics of the research staff and the depth of interaction between science and business have the greatest statistically significant effect on the target variable.

The studies of Dacko-Pikiewicz (2019), Kwilinski et al. (2022a), Pylaeva et al. (2022), Zhou et al. (2023) consider rates of the country's economic growth as a determinant to increase the efficiency of management of development in business process digitalization. In general, the influence of the Fourth Industrial Revolution (Büchi et al., 2020) and the active integration of economic processes worldwide contributed to the stimulation of innovative entrepreneurship (Dzwigol et al., 2020; Afawubo & Noglo, 2022). The state is responsible for the administration system, modern infrastructure organization, and maintaining an innovative technological environment. The key features of ensuring the effectiveness of the country's management of technological development are macroeconomic stability, fiscal support for innovative entrepreneurship, well-developed transport and telecommunications infrastructure, a low level of corruption, and liberal legislation.

The difficulty in forecasting a country's economic well-being under conditions of uncertainty and global structural transformations is noted as a factor that should be considered when managing the country's technological development (Dzwigol, 2021).

In the works of Guerrini et al. (2020) and Mendoza et al. (2022), a quantitative assessment of transformations in some European countries' socioeconomic and political development was carried out via bifurcation theory. The obtained results proved that, in Italy and France, for example, the stability of socioeconomic and technological development is primarily determined by the influence of external factors.

The interactions among economic agents, financial institutions and the real sector of the economy in managing the country's technological development are considered in the articles of Shi et al. (2023), Wonglimpiyarat (2019), Xiao et al. (2023), and Zhang et al. (2022). The paper proposes a model that formalizes the correlations between fluctuations in the country's financial development, changes in public trust in public authorities and the financial sector, and large shifts in business cycles, taking into account the countries' technological development.

In the work of Bonaccorsi et al. (2022), on the basis of data from 35 European countries for the period of 2014–2020, the relationships between three determinants were formalized via structural modelling: (1) the level of technological leadership and scientific activity effectiveness (14 indicators were used for measurement); (2) the level of economic development (11 indicators); and (3) the level of social development (8 indicators).

The works of Ali et al. (2023), Cho and Cantwell (2024), Delorme (2023), Faqih (2022), Ramadan et al. (2023), Trzeciak et al. (2022) proposed an innovation transfer model, "science – production – business", for the effective management of the country's technological development and analysed the landscape of development and implementation of innovations, considering the readiness of the population to accept them. These studies emphasize the role of the country's economic well-being in ensuring technological progress and effective management of the country's technological development. These researchers argue that well-functioning economic systems characterized by market competition, the protection of property rights, and economic freedom have more opportunities to facilitate innovation and technological progress than other systems do.

2.2. The impact of investments on the effectiveness of the country's management of technological development

Foreign direct investment (FDI) is a crucial determinant of a country's technological leadership, as it provides additional capital to strengthen technological potential, particularly in developing economies.

Viglioni et al. (2023) identify functional limitations affecting investment activity, the formation of investors' resource bases, and the direction of investment resources. Boitan and Ștefoni (2023), Han et al. (2019) emphasize that a significant barrier to attracting FDI to stimulate technological progress in EU countries is the extensive level of the shadow economy. The dynamics of foreign investment flows to a country are determined by its investment attractiveness, which primarily depends on the safety of investment activities, the transparency of the investment environment, and the openness of the economy.

The role of external investments in scaling businesses to increase their technological readiness for modern challenges, such as the transformation from SMEs, was studied by Vetrova et al. (2020), Dzwigol et al. (2019a, 2019b), Xiao et al. (2023), Rodrigues et al. (2023), Ziabina and Dzwigol-Barosz (2022). Dzwigol and Dzwigol-Barosz (2020), Kwilinski (2024), Kwilinski et al. (2024), Mesagan and Chidi (2020), Moskalenko et al. (2022a, 2022b), and Omri (2020) explored how investment mechanisms impact sustainable development. Researchers have found that the implementation of an investment project depends on the political and economic situation of the country. Investors evaluate the country's political and economic environment before deciding to cooperate, while the investment recipients decide whether to accept the investors' terms for further collaboration.

Park and Yang (2021), Tello-Gamarra and Fitz-Oliveira (2023) assessed the dominant instruments of innovation financing in different countries, as well as the primary directions of foreign investment flows.

Thus, economic prosperity and foreign investment are pivotal in determining a country's technological leadership. A strong economic base can support innovation, research, and development, whereas foreign investment can bring in resources and expertise that drive technological progress.

The current literature establishes that technological FDI often targets countries with developed institutional and technological frameworks, illustrating a conglomerate effect where developed environments attract substantial foreign investments. However, this also raises questions about the role of FDI in either sustaining or catalysing technological advancement. Previous research has focused primarily on the correlation between economic prosperity and technological innovation, often overlooking the distinct role that FDI plays. For example, studies by Loukil (2016), Sivalogathasan and Wu (2014), Walz (1997) have primarily discussed technological advancement through the lens of GDP growth and domestic resource allocation. In contrast, this study delves into how FDI uniquely contributes to technological leadership, providing a comparative analysis that highlights the scarcity of comprehensive research in this specific area.

Unlike García et al. (2013), who examined the impact of ICT usage on technological leadership without a distinct emphasis on FDI, our study integrates the effects of both inwards and outwards FDI flows, offering a more nuanced understanding of their role in technological innovation. Alazzawi (2012) and Wang et al. (2021) highlighted the contribution of high-tech goods exports to economic growth, focusing primarily on domestic capabilities. In contrast, our approach includes these exports but further links them to FDI effects, providing a broader scope of analysis on how external economic engagements impact technological standing.

Moreover, this study expands on the findings of Novotná et al. (2021), who discussed investment environments without linking them specifically to technological outputs. By integrating these variables into our stochastic frontier models, we provide a more comprehensive view that directly connects investment climates with technological efficiency, thus filling a significant gap left by previous studies.

This detailed comparison and analysis underscore the distinctiveness of our approach and contribution to the literature, which specifically investigates the dual role of FDI alongside domestic production in shaping technological leadership, an aspect that has received limited direct focus in existing research.

3. Data and methodology

This study is devoted to identifying which of the two factors (a high level of domestic aggregate production or the inflow of foreign direct investment) is decisive for ensuring the technological leadership of countries with a high GDP per capita. Stochastic frontier analysis is chosen as the main tool for this analysis. The true fixed effects stochastic frontier model is built on panel data on the basis of the Cobb–Douglas production and translogarithmic functions.

For the first time, a stochastic model was built by a group of scientists (Aigner et al., 1977), who presented the specification of the production function of the enterprise and analysed its efficiency. Later, Battese and Coelli (1992, 1995), Kumbhakar and Lovell (2000) devoted their research to a more in-depth study of stochastic frontier analysis.

A peculiarity of the frontier model is obtaining a certain efficiency limit on the basis of a predefined specification of its functional form and directly adding random components to the model. When a stochastic frontier model is constructed, the need to choose a functional form of the production frontier that best describes the competitive advantages of one country over another comes to the forefront. When choosing the functional form of the frontier, one should pay attention to the significant dependence between the output and input parameters, which contributes to increasing the competitive advantages of the countries under study, the principle of approximating the existing production limits of the functional form, and the possibility of linearizing the functional form of the dependence between the research parameters if necessary. In total, the stochastic frontier model can include two components of the random term:

- The first component, reflecting the influence of random factors;
- The second component, reflecting the ineffectiveness of the development of the phenomenon under study.

The distribution law of the random inefficiency components is chosen directly during the study and determined during the model specification's formation. Stochastic frontier analysis is based on the main provisions of the theory of production possibility sets, defined boundaries of given sets and the theory of production functions. The key advantages of using frontier analysis include the fact that it gives the modelling a multifactorial character, the objectivity of the methodology, the ability to compare the obtained efficiency results, and the possibility of testing various hypotheses. However, despite some advantages of frontier analysis, it also has several disadvantages: the need to clearly define the specification of the functional efficiency limit and the distribution law of model inefficiency.

The popularity of the Cobb–Douglas production function in scientific research is due to the small number of parameters and the possibility of linearizing the parameters logarithmically. This function is classically presented in Equation (1):

$$y_i = f(x,\beta) = \beta_0 \prod_{i=1}^{N} x_i^{\beta_i}, \tag{1}$$

where y_i is the resulting model variable; x is a set of input factor variables of the i subject for the N-year; β is an unknown parameter of the production function.

The most common way of forming the specification of a stochastic frontier model is the translogarithmic function. It is quadratic in its arguments and allows taking into account the nonmonotonic dependence of the output parameters on the input parameters. In addition, it also allows the linear representation of the input variables. The translogarithmic function is presented in the form of Equation (2):

$$f(x,\beta) = \beta_0 + \sum_{i=1}^{N} \beta_i \ln(x_i) + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \beta_{ij} \ln(x_i) \ln(x_j),\ \beta_{ij} = \beta_{ij}. \tag{2}$$

The final stochastic frontier model in its general form in the context of this study is presented in Equations (3)–(6):

$$\log(y_{it}) = f(x_{it},\beta) + \varepsilon_{it}; \tag{3}$$

$$\varepsilon_{it=v_{it}+u_{it}}; \tag{4}$$

$$u_{it} \geq 0; \quad (5)$$

$$v_{it} \sim N\left(0, \sigma_v^2\right); \quad (6)$$

$$I = 1, \ldots, N;\ t = 1, \ldots, T,$$

where y_{it} is the general level of technological development of i countries in period t; x_{it} is a set of input parameters that describe the change in the countries' technological development; ε_{it} is the technical efficiency of i-country for t-year within (0;1]; v_{it} is the stochastic error parameter; u_{it} is a parameter of technical inefficiency or unilateral error.

An important step in stochastic analysis is null hypothesis testing: $H0$: $\gamma = 0$ (a significant random or systematic technical inefficiency).

$$\gamma = \frac{\sigma_u^2}{\sigma^2}. \quad (7)$$

σ_u^2 is the technical inefficiency or one-sided error variance $u_{it,}$ and σ^2 is the total error variance.

During stochastic frontier modelling, a distinction is made between time-invariant and nontime-invariant stochastic models.

The time-invariant inefficiency model is characterized by the inefficiency parameter u_{it}, which is constant in time and distributed according to the normal distribution law (with its own µ value and variance σ^2).

The time-varying decay model is a truncated random variable distributed according to the normal distribution law multiplied by a function of time that varies depending on the decay coefficient (η): if it > 0, the degree of inefficiency decreases over time; if it < 0, it increases. If this parameter is equal to 0, the model is simplified to a time-invariant inefficiency model (Pillai, 2019; Kharazishvili et al., 2021).

Within the scope of this article, when constructing the time-invariant inefficiency model, the value $\eta = 0$ was obtained. Therefore, the time-invariant inefficiency model is used.

Before applying stochastic frontier analysis, exploratory factor analysis (EFA) was used to select relevant variables for the study. This allows the initial parameters closely correlated with each other to be combined into separate integrated factors, thereby reducing their number. When analysing the formed data array of indicators of countries' technological development, it is crucial to identify the adequacy of the selected data sample. The authors use the Bartlett test, which demonstrates significant relationships between variables on the basis of correlation matrix analysis. The Kaiser–Meyer–Olkin (KMO) criterion allows the calculation of the share of variance of variables caused by the main factor.

The input data in this study include nineteen indicators: fourteen indicators characterizing the countries' technological development and five key indicators of the countries' economic development. These indicators, their notations and units of measurement are presented in Table 1.

Table 1. The array of input data

Symbol	Notation	Indicator	Unit of measurement	Resource
Y	*Res_dev*	Research and development expenditure	% of GDP	World Development Indicators, World Bank n.d.
x1	*tech1*	Export of communications, computer, information, and other services cover international telecommunications; computer data	% of service exports	
x2	*tech2*	Import of communications, computer, information, and other services cover international telecommunications; computer data	% of service imports	
x3	*tech3*	Export of computer, communications and other services (international telecommunications, and postal and courier services; computer data; news-related service transactions, technical services)	% of commercial service exports	
x4	*tech4*	Import of computer, communications and other services (international telecommunications, and postal and courier services; computer data; news-related service transactions, technical services)	% of commercial service imports	
x5	*tech5*	High-technology exports	$	
x6	*tech6*	ICT goods exports	% of total goods exports	
x7	*tech7*	ICT goods imports	% of total goods imports	
x8	*tech8*	ICT service exports	% of service exports	
x9	*tech9*	2ICT service exports	$	
x10	*tech10*	Individuals using the Internet	% of population	
x11	*tech11*	Patent applications, residents	units	
x12	*tech12*	Patent applications, nonresidents	units	
x13	*tech13*	Global Innovation Index	units	World Intellectual Property Organization (WIPO) (2023)
u1	*econ1*	GDP per capita	$	World Development Indicators, World Bank n.d.
u2	*econ2*	GNI per capita	$	
u3	*econ3*	Inflation, consumer prices	annual %	
u4	*econ4*	Foreign direct investment, net inflows	% of GDP	
u5	*econ5*	Foreign direct investment, net outflows	% of GDP	

On the basis of the presented indicators, panel data were formed by country, year of research and specific indicators.

According to the World Bank classification, the study was conducted in 21 developed countries (Western Europe, America, Asia, Africa, and Australia). The available and necessary statistical support for a certain period determines the choice of exactly this number of countries. The sample of research countries included Austria, Belgium, the United Kingdom, Germany, Ireland, Luxembourg, the Netherlands, France, Italy, Switzerland, Finland, Sweden, the USA, Canada, China, Japan, South Korea, Singapore, New Zealand, South Africa, and Australia.

The analysis delves into the mechanisms through which GDP per capita impacts technological efficiency. While in developed countries, a high GDP per capita may sometimes lead to complacency and reduced innovation – termed the 'resource curse' – in developing nations, increases in GDP per capita could catalyze technological development by funding essential infrastructure and education that indirectly support innovation.

The study period covers twelve years, from 2011 to 2022. The availability of data also affects the selected research period. The World Bank n.d. World Development Indicators database, in terms of technological and economic development indicators, and data of the World Intellectual Property Organization (2023), in terms of the Global Innovation Index, were used as the input information base.

All calculations for this study were performed with the StataSE 18 software package.

4. Results

A comprehensive study first requires analysing the key descriptive statistics for the panel data. The descriptive statistics for the indicators of the countries' technological and economic development are presented in Table 2 and Table 3.

A panel data sample was formed, including 252 observations for this study. There are no missing data in the array. The values of the analysed parameters of technological and economic development have different units of measurement, and some of them show significant data variation. The maximum value of the R&D expenditure indicator exceeds the minimum value by approximately 13 times. Figure 1 presents a graphical view of the variation in the value of the R&D expenditure indicator.

The studied countries can be divided into four groups according to the level of R&D expenditure:

- The first group includes South Africa, with the lowest value of research and development expenditure (from 0.4% to 0.76% of GDP);
- The second group of countries includes Luxembourg, New Zealand, Ireland, Italy, the United Kingdom, Canada, Singapore, Australia, China, the Netherlands, France, and Belgium, for which research and development expenditures range from 1% to 2.5% of GDP;
- The third group includes Austria, the United States, Finland, Germany, Switzerland, and Sweden (research and development expenditures vary between 2.5% and 4% of GDP);
- The fourth group included one leading country, according to the level of research and development expenditure – 4% to 5.2% of GDP.

Table 2. Descriptive statistics for indicators of technological development

Variable		Mean	Standard deviation	Minimum	Maximum	Observations
Res_dev	overall	2.330	0.929	0.401	5.189	N = 252 n = 21 T = 12
	between		0.917	0.639	4.323	
	within		0.242	1.598	3.593	
tech1	overall	50.546	15.657	16.644	85.523	
	between		15.023	25.295	75.649	
	within		5.417	40.894	73.403	
tech2	overall	50.897	14.507	18.940	87.610	
	between		13.568	26.697	82.505	
	within		5.869	37.706	74.554	
tech3	overall	50.405	15.744	17.014	86.090	
	between		14.994	26.041	76.735	
	within		5.737	41.163	75.156	
tech4	overall	50.482	14.927	18.558	89.874	
	between		14.055	26.227	84.367	
	within		5.826	37.161	73.913	
tech5	overall	94.158	151.743	0.564	942.315	
	between		152.512	0.753	702.781	
	within		28.022	–68.455	333.692	
tech6	overall	7.372	8.708	0.675	34.714	
	between		8.817	1.032	31.187	
	within		1.224	0.897	12.911	
tech7	overall	9.768	5.900	3.118	32.877	
	between		5.899	3.581	27.396	
	within		1.243	5.296	15.248	
tech8	overall	11.422	10.586	1.391	58.950	
	between		10.493	3.208	47.376	
	within		2.605	3.604	22.995	
tech9	overall	18.404	25.547	0.545	206.351	
	between		22.043	0.653	99.974	
	within		13.714	–40.201	124.780	
tech10	overall	84.203	12.436	33.970	98.661	
	between		11.106	56.175	95.987	
	within		6.059	61.540	104.305	
tech11	overall	88611.750	244512.700	58.000	1426644.000	
	between		237641.300	71.179	1059304.000	
	within		76078.920	–554862.800	455952.200	
tech12	overall	31491.330	69276.460	32.000	336340.000	
	between		70538.090	50.544	305512.800	
	within		6454.513	–18189.420	62318.580	
tech13	overall	15.492	12.787	1.000	63.000	
	between		12.605	1.000	58.167	
	within		3.405	3.909	27.909	

Note: overall – information on the general array of data, between – information on the variation of variables between 21 countries; within – information on how the variable varies over 12 years, ignoring all variation between units.

Table 3. Descriptive statistics for indicators of economic development

Variable		Mean	Standard deviation	Minimum	Maximum	Observations
econ1	overall	5.006	2.383	0.561	13.359	N = 252 n = 21 T = 12
	between		2.364	0.694	11.705	
	within		0.580	2.802	8.301	
econ2	overall	4.339	1.857	0.339	8.795	
	between		1.854	0.379	8.018	
	within		0.402	2.863	6.242	
econ3	overall	2.043	2.012	–1.144	10.001	
	between		0.942	0.188	5.203	
	within		1.788	–0.339	9.639	
econ4	overall	3.779	32.458	–391.437	234.466	
	between		7.180	–7.124	23.904	
	within		31.689	–380.534	245.369	
econ5	overall	5.539	31.355	–322.033	253.155	
	between		8.268	–0.064	35,543	
	within		30.295	–352.038	223.150	

Note: overall – information on the general array of data, between – information on the variation of variables between 21 countries; within – information on how the variable varies over 12 years, ignoring all variation between units.

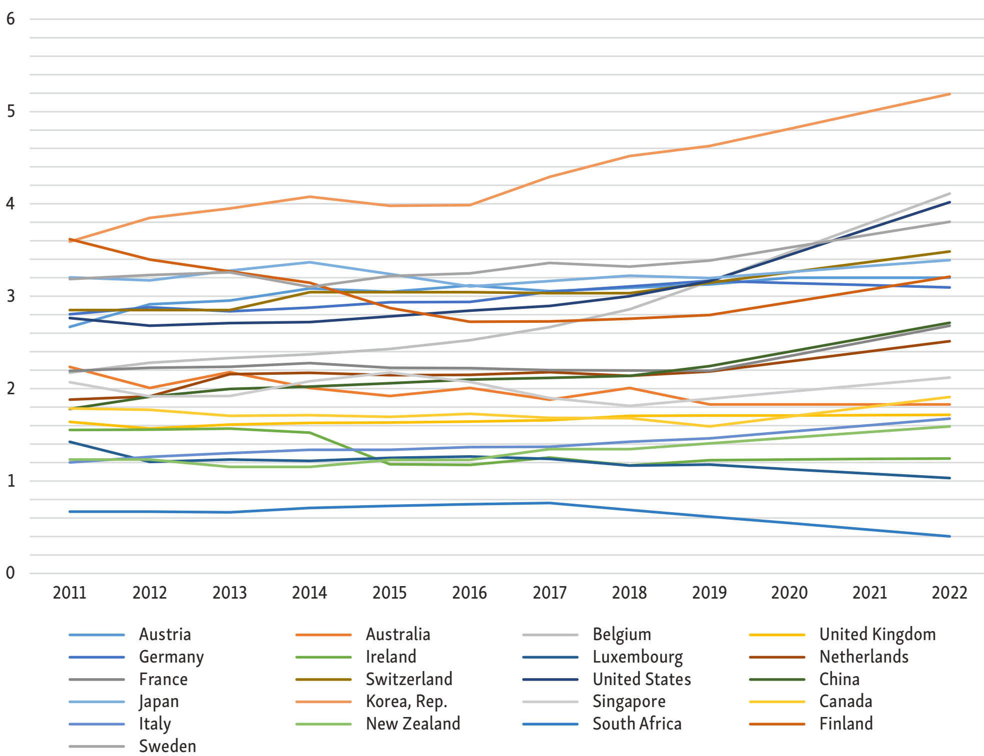

Figure 1. Dynamics of changes in the research and development expenditure indicator for 21 countries from 2011–2022 (source: created by authors from the World Bank, n.d.)

A comparison of the values of R&D expenditure and GDP per capita of the countries participating in this study, as of 2022, reveals (Figure 2) that, in countries with greater technological development, GDP per capita is not proportional.

The results of the EFA are presented in Table 4.

The Kaiser–Meyer–Olkin (KMO) criterion should be used to determine the optimal number of factors. This criterion allows us to calculate the share of variance of variables caused by the main factors. If the Kaiser–Meyer–Olkin (KMO) criterion for a factor is greater than or equal to 1, the corresponding factor must be left for further analysis. This criterion is based on constructing a scree plot (Figure 3). The dotted line on the graph marks the place where the Kaiser–Meyer–Olkin (KMO) criterion is equal to 1. Thus, further selection of relevant indicators of technological development will take place from the first three factors, which explain more than 76% of the total variance (Table 4).

Table 4. EFA results for the technological development indicators

Factor	Eigenvalue	Proportion	Cumulative proportion
Factor 1	4.771	0.367	0.367
Factor 2	3.712	0.286	0.653
Factor 3	1.427	0.110	0.762
Factor 4	0.978	0.075	0.838
Factor 5	0.711	0.055	0.892
Factor 6	0.525	0.040	0.933
Factor 7	0.310	0.024	0.956
Factor 8	0.263	0.020	0.977
Factor 9	0.182	0.014	0.991
Factor 10	0.077	0.006	0.997
Factor 11	0.039	0.003	1.000
Factor 12	0.004	0.000	1.000
Factor 13	0.001	0.000	1.000

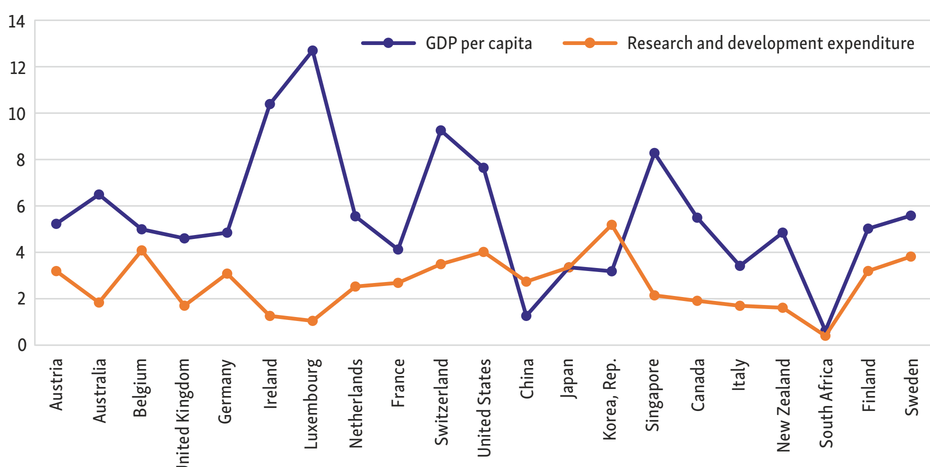

Figure 2. Dynamics of changes in research and development expenditures and GDP per capita for 21 countries in 2022 (source: created by authors from the World Bank, n.d.)

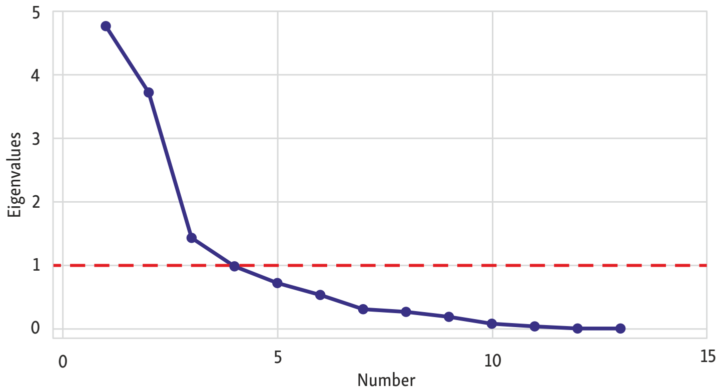

Figure 3. Scree plot of the eigenvalues for the technological development indicators (Kaiser–Meyer–Olkin (KMO) criterion)

The first three factors include a set of input parameters of technological development with a certain factor load. The factor loadings of the technological development indicators that were regrouped between the first three factors (without rotation) are presented in Table 5.

Table 5. Factor loadings of technological development indicators for Factors 1–3 (without rotation)

Variable	Factor 1	Factor 2	Factor 3	Unexplained
tech1	0.441	0.373		0.133
tech2	0.318			0.150
tech3	0.551	0.365		0.125
tech4	0.424			0.140
tech5		0.900		0.129
tech6		0.898	–0.337	0.242
tech7		–0.891	–0.329	0.246
tech8	0.757		0.406	0.251
tech9	0.548	0.359	0.349	0.450
tech10	0.523		–0.456	0.227
tech11		0.750		0.179
tech12		–0.913		0.576
tech13	–0.948		0.641	0.244

Note: variables with a factor loading of less than 0.3 are not included in the results table.

According to the factor loadings of the indicators in Table 5, five indicators should be selected for further analysis: *tech5* (High-technology exports), *tech6* (ICT goods exports), *tech7* (ICT goods imports), *tech12* (Patent applications, nonresidents) and *tech13* (Global Innovation Index). The selection of the listed indicators is also confirmed by their uniqueness, which is in the last column of Table 5 (the greater the value of uniqueness is, the lower the significance of the corresponding variable).

The redistribution of factor loading values after varimax rotation is presented in Table 6.

Given the results in Table 6, the redistribution of factor loads has not changed, and the five indicators of technological development listed above remain the same.

The EFA results for the economic development indicators are presented in Table 7.

The first two factors (Factor 1 and Factor 2) explain more than 70% of the total variance. This allows for a preliminary conclusion regarding the optimality of using these factors for further analysis. It is necessary to confirm or refute this assumption via the KMO criterion (Figure 4).

According to the graph presented in Figure 4, the KMO criterion is greater than 1 for the first two factors. This confirms the previous assumption about the optimality of the further analysis of only Factor 1 and Factor 2. The selection of relevant indicators of economic development, which act as adjusting variables determining the overall technological level of development of the countries under study, is based on their factor loadings presented in Table 8 (without rotation).

According to the factor loadings of the indicators in Table 8, it is sufficient to select all three indicators of economic development for further analysis: *econ1* (GDP per capita), *econ4* (foreign direct investment, net inflows) and *econ5* (foreign direct investment, net outflows). The choice of the listed indicators is also confirmed by the uniqueness, which is in the last column of Table 8 (the greater the value of uniqueness is, the lower the significance of the corresponding variable).

Table 6. Factor loadings of indicators of technological development for Factors 1–3 (with varimax rotation)

Variable	Factor 1	Factor 2	Factor 3	Unexplained
tech1	0.402			0.133
tech2	0.304		0.374	0.150
tech3	0.507			0.125
tech4	0.412		0.366	0.140
tech5		0.903		0.129
tech6		0.840		0.242
tech7		–0.843		0.246
tech8	0.853			0.251
tech9	0.704			0.450
tech10			0.818	0.227
tech11		0.751	–0.311	0.179
tech12		–0.941		0.576
tech13	–0.928		–0.782	0.244

Note: variables with a factor loading of less than 0.3 are not included in the results table.

Table 7. EFA results for economic development indicators

Factor	Eigenvalue	Proportion	Cumulative proportion
Factor 1	1.954	0.391	0.391
Factor 2	1.566	0.313	0.704
Factor 3	0.967	0.193	0.897
Factor 4	0.382	0.076	0.974
Factor 5	0.132	0.027	1.000

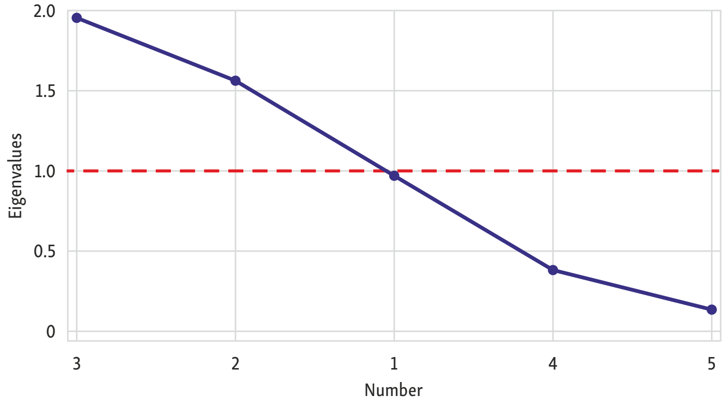

Figure 4. Scree plot of eigenvalues for economic development indicators (Kaiser–Meyer–Olkin (KMO) criterion)

Table 8. Factor loadings of economic development indicators for Factor 1 and Factor 2 (without rotation)

Variable	Factor 1	Factor 2	Unexplained
econ1	0.412	0.804	0.184
econ2	0.396	0.790	0.218
econ3	–0.305		0.906
econ4	0.843	–0.457	0.081
econ5	0.907		0.091

Note: indicators with a factor loading of less than 0.3 are not included in the results table.

Table 9. Factor loadings of economic development indicators for Factors 1–3 (with varimax rotation)

Variable	Factor 1	Factor 2	Unexplained
econ1	0.903		0.184
econ2	0.884		0.218
econ3		–0.247	0.906
econ4	0.957		0.081
econ5	0.946		0.091

Note: variables with a factor loading of less than 0.3 are not included in the results table.

The redistribution of factor loading values after varimax rotation is presented in Table 9.

Given the results in Table 9, the redistribution of factor loadings for economic development indicators has not changed. The three indicators of economic development play the role of adjustment variables during the construction of stochastic frontier analysis.

Thus, in SFA, the specification of the model has the following form (8).

$$\log\left(\mathrm{Re}\,s_{devit}\right) = \beta_1 \log tech5 + \beta_2 \log tech6 + \beta_3 \log tech7 + \beta_4 \log tech12 + \beta_5 \log tech13 + \varepsilon_{it}. \quad (8)$$

In Equation (7), ε_{it} includes four different parameters of technical inefficiency: *econ1* (GDP per capita), *econ4* (foreign direct investment, net inflows) and *econ5* (foreign direct investment, net outflows). Thus, four stochastic frontier models are built. The modelling results are presented in Tables 10–12.

Table 10. Results of the stochastic frontier analysis with the technical inefficiency parameter *econ1* (GDP per capita)

Variables	Coefficient	Stand. error	z	P > z	95% conf. interval	
logtech5	0.918	0.266	3.450	0.001	0.397	1.440
logtech6	0.200	0.289	0.690	0.490	0.367	0.766
logtech7	–3.098	0.448	–6.920	0.000	–3.975	–2.221
logtech12	–0.634	0.131	–4.850	0.000	–0.891	–0.378
logtech13	–0.795	0.108	–7.390	0.000	–1.006	–0.584
year	0.015	0.001	29.870	0.000	0.014	0.016
econ1	9.955	1.229	8.100	0.000	7.545	12.364
cons	–146.057					
Usigma cons	3.033	0.388	7.810	0.000	2.271	3.794
Vsigma cons	–1.694	0.217	–7.790	0.000	–2.120	–1.268
sigma_u	4.555	0.885	5.150	0.000	3.113	6.666
sigma_v	0.429	0.047	9.200	0.000	0.346	0.530
lambda	10.626	0.915	11.610	0.000	8.833	12.420

The frontier analysis results in Table 10 demonstrate that at a given confidence level of 0.95 among the factor features, *tech5* has a statistically significant positive effect on *Res_dev* – with an increase in high-technology exports of 1%, research and development expenditures increase by more than 0.9%. Variables such as *tech7*, *tech12* and *tech13* negatively affect research and development expenditures (with an increase in ICT goods imports of 1%, research and development expenditures decrease by more than 3%, and with an increase in patent applications, nonresidents decrease by 1%). Research and development expenditures decrease by more than 0.6%, with an increase in the global innovation index of 1%. Research and development expenditures decrease by almost 0.8%. The positive statistically significant value of the regression coefficient near the year parameter indicates that during the observed period, there is a positive trend in the value of R&D expenditure.

The regression coefficient near *the econ1* indicator is equal to 9.955 and is statistically significant (*p value* is less than 0.05). This means that the growth of GDP per capita contributes to the growth of the technical inefficiency of the system; i.e., the increase in GDP per capita has a negative effect on the development of R&D expenditures.

Testing of the null hypothesis, *H*0: $\gamma = 0$, about significant random or systematic technical inefficiency, resulted in the following: the calculated value of γ for this stochastic frontier model is 0.99. The obtained result means that 99% of the total model variation is due to technical inefficiency, and only 1% is statistical noise. This allows you to reject the null hypothesis.

As a result of the construction of two frontier models, where the technical inefficiency parameters are the variables *econ4* (foreign direct investment, net inflows) and *econ5* (foreign direct investment, net outflows), the following results were obtained:

- An increase in the variable *tech5* (high-technology exports) of 1% causes an increase in research and development expenditure of almost 0.2% (statistically significant effect);
- An increase in the variable *tech13* (Global Innovation Index) of 1% causes a decrease in research and development expenditure of less than 0.1% (statistically significant effect);

- The regression coefficient near the year parameter is statistically significant, which confirms the importance of the trend component;
- The negative value of the statistically significant regression coefficients near the parameters *econ4* (foreign direct investment, net inflows) and *econ5* (foreign direct investment, net outflows) means that flows of foreign direct investment have a positive effect on the technical efficiency of the system and, accordingly, on the increase in the volume of R&D expenditure.

Table 11. The results of the stochastic frontier analysis with the technical inefficiency parameter *econ4* (foreign direct investment, net inflows)

Variables	Coefficient	Stand. error	z	P > z	95% conf. interval	
logtech5	0.187	0.034	5.460	0.000	0.120	0.254
logtech6	0.052	0.042	1.240	0.215	–0.030	0.133
logtech7	–0.081	0.075	–1.080	0.278	–0.227	0.065
logtech12	–0.018	0.016	–1.120	0.264	–0.050	0.014
logtech13	–0.091	0.018	–5.000	0.000	–0.126	–0.055
year	0.012	0.002	6.310	0.000	0.008	0.016
econ4	–0.070	0.167	–6.420	0.005	–0.398	0.258
cons	–73.456	122.103	–0.600	0.547	–312.774	165.862
Usigma cons	1.747	1.663	1.050	0.293	–1.512	5.006
Vsigma cons	–6.326	0.350	–18.060	0.000	–7.013	–5.639
sigma_u	2.395	1.991	1.200	0.229	0.470	12.219
sigma_v	0.042	0.007	5.710	0.000	0.030	0.060
lambda	56.624	1.992	28.430	0.000	52.720	60.528

Table 12. The results of the stochastic frontier analysis with the technical inefficiency parameter *econ5* (foreign direct investment, net outflows)

Variables	Coefficient	Stand. error	z	P > z	95% conf. interval	
logtech5	0.187	0.034	5.490	0.000	0.120	0.254
logtech6	0.053	0.041	1.280	0.201	–0.028	0.134
logtech7	–0.083	0.074	–1.120	0.263	–0.229	0.062
logtech12	–0.018	0.016	–1.190	0.235	–0.049	0.012
logtech13	–0.091	0.018	–5.050	0.000	–0.127	–0.056
year	0.012	0.002	6.340	0.000	0.008	0.016
econ5	–0.091	0.317	–6.290	0.003	–0.712	0.530
cons	–53.517	182.026	–0.290	0.769	–410.282	303.249
Usigma cons	1.428	3.391	0.420	0.674	–5.218	8.074
Vsigma cons	–6.315	0.346	–18.270	0.000	–6.993	–5.638
sigma_u	2.042	3.463	0.590	0.555	0.074	56.654
sigma_v	0.043	0.007	5.790	0.000	0.030	0.060
lambda	48.028	3.463	13.870	0.000	41.241	54.814

When the null hypothesis is tested ($H0$: $\gamma = 0$), the calculated value of γ for both stochastic frontier models is 0.99. The obtained result means that 99% of the total model variation is due to technical inefficiency, and only 1% is statistical noise. This allows one to reject the null hypothesis.

Stochastic frontier analysis allows us to obtain the technical efficiency, which characterizes, in this case, the technical efficiency of the technological development of highly developed countries. The dynamics of changes in the technical efficiency of the technological development of developed countries in 2011, 2017 and 2022 are presented in Figure 5.

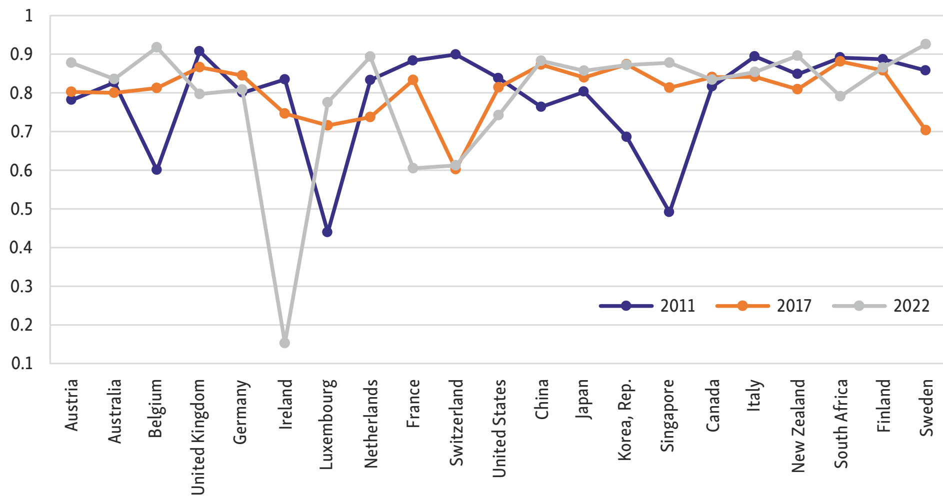

Figure 5. Dynamics of changes in the technical efficiency of the technological development of developed countries in 2011, 2017 and 2022

The year 2017 was the most stable from the point of view of the technical efficiency of the studied countries' technological development. During this year, developed countries' technical efficiency ranged from 0.6 (Switzerland) to 0.88 (South Africa). In 2011, the technical efficiency range varied from 0.44 (Luxembourg) to 0.9 (UK). In addition, this year, the group of outsiders in terms of the technical efficiency of technological development included Singapore, Belgium, South Korea, China, and Austria, which demonstrated high technological development in 2017 and 2022. In 2022, the technical efficiency range varied from 0.15 (Ireland) to 0.93 (Sweden). Compared with 2017, there was a decrease in the level of technical efficiency of technological development in France, the USA, South Africa and Great Britain, as illustrated in Figure 5, which summarizes the dynamics of technical efficiency for 2011, 2017, and 2022.

5. Conclusions

Within the scope of this study, a hypothesis was proposed and empirically confirmed that countries with high GDP per capita are technological leaders not because of a high level of domestic aggregate production but because of the inflow of foreign direct investments. The research was conducted on the data of 21 developed countries (Western Europe, America, Asia, Africa, and Australia), and the specific group of countries in the sample was included owing to the availability of relevant statistical data for 2011–2022 in the following databases: the database of the World Bank n.d. Development Indicators (in terms of technological and economic development indicators) and data of the World Intellectual Property Organization (2023) (in terms of the Global Innovation Index) were used as the input information base.

The relevant indicators were selected with the help of exploratory factor analysis:

- Five indicators of technological development (high-technology exports, ICT goods exports, ICT goods imports, patent applications, nonresidents and the global innovation index);
- Three indicators of economic development (GDP per capita, foreign direct investment, net inflows, foreign direct investment, net outflows) are used.

All the listed variables are included in stochastic frontier analysis as independent (indicators of technological development) and corrective (indicators of economic development) variables. The Research and Development expenditure indicator performs the role of the dependent variable.

In total, three frontier models are constructed in this study.

The results of the first frontier model, where GDP per capita was the adjustment variable, showed that the growth of GDP per capita contributes to the growth of technical inefficiency, i.e., it negatively affects technological development. At the same time, it is worth noting the following functional dependencies: with an increase in high-technology exports of 1%, research and development expenditures increase by more than 0.9%; with an increase in ICT goods imports of 1%, research and development expenditures decrease by more than 3%; with an increase in patent applications, nonresidents decrease by 1%, research and development expenditures decrease by more than 0.6%, and with an increase in the global innovation index of 1%, research and development expenditures decrease by almost 0.8%.

The second and third frontier models with the adjustment variables Foreign direct investment, net inflows and Foreign direct investment, and net outflows, respectively, showed that foreign direct investment flows positively affect the technical efficiency of the studied system, i.e., the countries' technological development. The following relationships determine the change in the dependent variable for the second and third models: an increase in high-technology exports of 1% causes an increase in research and development expenditures of almost 0.2%; an increase in the global innovation index of 1% causes a decrease in research and development expenditures of less than 0.1%.

Thus, on the basis of the results of the stochastic frontier analysis, the technological development of economically developed countries is determined not by high domestic aggregate production but by the inflow of foreign direct investments. Therefore, when reviewing the key determinants of technological development management in economically developed countries, one should consider that today, the activation of external investment flows contributes to creating technological centers or clusters where innovations and technological development are concentrated. Such centers become centers of excellence, attracting additional investments. The infusion of foreign capital and technology and the use of new methods of technological development management increase the country's ability to compete in the world market and contribute to cooperation and the creation of networks between local and foreign firms, research institutions and universities. This collaboration plays an essential role in driving technological progress through joint research and development initiatives.

As noted in the previous Sections, several researchers noted that developing countries often face a shortage of capital and technological knowledge necessary for the effective management of technological development processes. In this context, attracting foreign direct investment can provide additional financial resources and technologies, which, in turn, contributes to the more efficient development of these countries.

Foreign investment can lead to the creation of new industries and businesses, jobs and increased employment in developing countries.

Transnational corporations may also consider the importance of their technological development of foreign direct investment, as it allows them to expand their market reach. They can access new consumers and diversify their revenue streams by investing in foreign markets. Direct investment in technological development management in other countries allows multinational corporations to integrate these regions into their global supply chains, potentially reducing costs and increasing efficiency.

Investors, including institutional investors and individual shareholders, may consider the influence of foreign direct investment significant for managing technological development, as it opens up opportunities to diversify investment portfolios. Investing in technology in different regions can spread risk and yield higher returns.

As previously noted, the impact and appropriateness of technological development driven by FDI may vary depending on the specific conditions of each country or region. For policymakers and other stakeholders, it is crucial to find an optimal balance between the benefits of foreign investment and concerns regarding economic sovereignty, dependence, and potential negative social and environmental consequences.

This study's findings have significant strategic implications for policymakers, especially in developing economies. While developed countries attract foreign direct investment (FDI) due to their advanced economic status, developing nations can use incremental GDP growth as a strategic asset to enhance their technological infrastructures and attract quality FDI. Therefore, effective policies should focus on improving institutional stability and technological readiness to maximize the developmental impacts of FDI.

This study highlights the critical role of FDI in enhancing technological leadership in countries with high GDP per capita, which is distinct from their domestic production capabilities. However, like all research, this study has certain limitations that warrant mention and provide avenues for future research.

One primary limitation of this research is the assumption that technological advancements driven by FDI are uniformly beneficial across all sectors within the economies studied. In reality, the impact of FDI can vary greatly depending on the sector and the existing technological infrastructure. Additionally, our analysis is constrained by the availability and reliability of data across different countries and years, which may affect the generalizability of the findings. Moreover, the economic models employed, while robust, do not capture noneconomic factors such as political stability and regulatory environments that can influence technological advancements.

To build on these findings, future research could explore the sector-specific impacts of FDI on technological advancements. The incorporation of qualitative data would provide deeper insights into the contextual factors influencing the effectiveness of FDI. Further studies could also examine the long-term sustainability of technological leadership driven by FDI, considering the evolving global economic landscape. Comparative studies between countries with similar economic statuses but different levels of FDI inflows could yield interesting contrasts and deeper understandings of the dynamics at play.

Although this study underscores the potential of FDI to enhance technological leadership, particularly in high GDP per capita countries, its applicability to developing nations requires careful consideration of specific local conditions. Developing countries often face unique challenges such as limited infrastructure, less political stability, and lower educational levels, which can hinder the effective utilization of foreign investments. To harness the full potential of FDI, it is crucial for policymakers in these countries to implement targeted reforms aimed at improving governance, infrastructure, and workforce skills. Future research could explore the impact of such reforms on maximizing the benefits of FDI, providing a comparative analysis across different developmental contexts. This nuanced approach acknowledges the significant work still required to replicate these benefits universally.

Moreover, future research should focus on examining the nuances of the relationships among economic well-being, foreign investment, and technological leadership in different national and regional contexts. Understanding the mechanisms through which these factors influence technological progress is critical for policymakers and stakeholders seeking to strengthen a country's position in the global technological landscape.

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References

Adrangi, B., & Kerr, L. (2022). Sustainable development indicators and their relationship to GDP: Evidence from emerging economies. *Sustainability*, *14*(2), Article 658. https://doi.org/10.3390/su14020658

Afawubo, K., & Noglo, Y. A. (2022). ICT and entrepreneurship: A comparative analysis of developing, emerging and developed countries. *Technological Forecasting and Social Change*, *175*, Article 121312. https://doi.org/10.1016/j.techfore.2021.121312

Aigner, D. J., Lovell, C. A. K., & Schmidt, P. (1977). Formulation and estimation of frontier production function models. *Journal of Econometrics*, *6*(1), 27–37. https://doi.org/10.1016/0304-4076(77)90052-5

Ali, O., Murray, P. A., Momin, M., Al-Anzi, F. S. (2023). The knowledge and innovation challenges of ChatGPT: A scoping review. *Technology in Society*, *75*, Article 102402. https://doi.org/10.1016/j.techsoc.2023.102402

Alazzawi, S. (2012). Innovation, productivity and foreign direct investment-induced R&D spillovers. *The Journal of International Trade & Economic Development*, *21*(5), 615–653. https://doi.org/10.1080/09638199.2010.513056

Amendolagine, V., Hansen, U. E., Lema, R., Rabellotti, R., & Ribaudo, D. (2023). Do green foreign direct investments increase the innovative capability of MNE subsidiaries? *World Development*, *170*, Article 106342. https://doi.org/10.1016/j.worlddev.2023.106342

Asafo-Agyei, G., & Kodongo, O. (2022). Foreign direct investment and economic growth in Sub-Saharan Africa: A nonlinear analysis. *Economic Systems*, *46*(4), Article 101003. https://doi.org/10.1016/j.ecosys.2022.101003

Asim, Z., & Sorooshian, S. (2019). Exploring the role of knowledge, innovation and technology management (KNIT) capabilities that influence research and development. *Journal of Open Innovation*: *Technology*, *Market*, *and Complexity*, *5*(2), Article 21. https://doi.org/10.3390/joitmc5020021

Ata, E., & Saltan, F. (2023). School principals' perspective on technological leadership, technostress and information and communication technology: A scoping review. *Participatory Educational Research*, *10*(5), 147–167. https://doi.org/10.17275/per.23.79.10.5

Awad, A., & Albaity, M. (2022). ICT and economic growth in Sub-Saharan Africa: Transmission channels and effects. *Telecommunications Policy*, *46*(8), Article 102381. https://doi.org/10.1016/j.telpol.2022.102381

Battese, G. E., & Coelli T. J. (1992). Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis*, *3*, 153–169. https://doi.org/10.1007/BF00158774

Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, *20*(2), 325–332. https://doi.org/10.1007/BF01205442

Boitan, I. A., & Ștefoni, S. E. (2023). Digitalization and the shadow economy: Impact assessment and policy implications for EU countries. *Eastern European Economics*, *61*(2), 152–180. https://doi.org/10.1080/00128775.2022.2102508

Büchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. *Technological Forecasting and Social Change*, *150*, Article 119790. https://doi.org/10.1016/j.techfore.2019.119790

Bonaccorsi, A., Blasi, B., Nappi, C. A., & Romagnosi, S. (2022). Quality of research as source and signal: Revisiting the valorization process beyond substitution vs complementarity. *Journal of Technology Transfer*, *47*(2), 407–434. https://doi.org/10.1007/s10961-021-09860-7

Carrasco, C. A., & Tovar-García, E. D. (2023). High-tech trade as determinant of the US bilateral trade balance. *Economics of Innovation and New Technology*, *32*(5), 713–730. https://doi.org/10.1080/10438599.2021.2018313

García, F., Jin, B., & Salomon, R. (2013). Does inward foreign direct investment improve the innovative performance of local firms? *Research Policy*, *42*(1), 231–244. https://doi.org/10.1016/j.respol.2012.06.005

Cho, S., & Cantwell, J. (2024). Knowledge sourcing and national technological development: The weak internationalization of R&D in South Korea. *Journal of Business Research*, *170*, Article 114345. https://doi.org/10.1016/j.jbusres.2023.114345

Dacko-Pikiewicz, Z. (2019). The selected aspects of strategic management in the city divided by the border in the context of the development of the cross-border market of cultural services. *Polish Journal of Management Studies*, *19*(1), 130–144. https://doi.org/10.17512/pjms.2019.19.1.10

Delorme, D. (2023). The role of proximity in the design of innovation intermediaries' business models. *Technological Forecasting and Social Change*, *188*, Article 122246. https://doi.org/10.1016/j.techfore.2022.122246

Dementyev, V. V., & Kwilinski, A. (2020). Institutional component of production costs. *Journal of Institutional Studies*, *12*(1), 100–116. https://doi.org/10.17835/2076-6297.2020.12.1.100-116

Dementyev, V., Dalevska, N., & Kwilinski, A. (2021). Innovation and information aspects of the structural organization of the world political and economic space. *Virtual Economics*, *4*(1), 54–76. https://doi.org/10.34021/ve.2021.04.01(3)

Dzwigol, H., Aleinikova, O., Umanska, Y., Shmygol, N., & Pushak, Y. (2019a). An entrepreneurship model for assessing the investment attractiveness of regions. *Journal of Entrepreneurship Education*, *22*(1S), 1–7.

Dzwigol, H., Shcherbak, S., Semikina, M., Vinichenko, O., & Vasiuta, V. (2019b). Formation of strategic change management system at an enterprise. *Academy of Strategic Management Journal*, *18*(1), 1–8.

Dzwigol, H., & Dzwigol-Barosz, M. (2020). Sustainable development of the company on the basis of expert assessment of the investment strategy. *Academy of Strategic Management Journal*, *19*(5), 1–7.

Dzwigol, H., Dzwigol-Barosz, M., & Kwilinski, A. (2020). Formation of global competitive enterprise environment based on Industry 4.0 concept. *International Journal of Entrepreneurship*, *24*(1), 1–5.

Dzwigol, H. (2021). The uncertainty factor in the market economic system: The microeconomic aspect of sustainable development. *Virtual Economics*, *4*(1), 98–117. https://doi.org/10.34021/ve.2021.04.01(5)

Fagbemi, F., & Osinubi, T. T. (2020). Leveraging foreign direct investment for sustainability: An approach to sustainable human development in Nigeria. *Resources*, *Environment and Sustainability*, *2*, Article 100005. https://doi.org/10.1016/j.resenv.2020.100005

Faqih, K. M. S. (2022). Factors influencing the behavioral intention to adopt a technological innovation from a developing country context: The case of mobile augmented reality games. *Technology in Society*, *69*, Article 101958. https://doi.org/10.1016/j.techsoc.2022.101958

Guerrini, L., Krawiec, A., & Szydłowski, M. (2020). Bifurcations in an economic growth model with a distributed time delay transformed to ODE. *Nonlinear Dynamics*, *101*, 1263–1279. https://doi.org/10.1007/s11071-020-05824-y

Han, X., Hus, S., & Li, J. (2019) The impact of enterprises' shadow banking activities on business performance: A test based on mediator effect of investment scale and investment efficiency. *Emerging Markets Finance and Trade*, *55*(14), 3258–3274. https://doi.org/10.1080/1540496X.2018.1525358

Hu, D., You, K., & Eşiyok, B. (2021). Foreign direct investment among developing markets and its technological impact on host: Evidence from spatial analysis of Chinese investment in Africa. *Technological Forecasting and Social Change*, *166*, Article 120593. https://doi.org/10.1016/j.techfore.2021.120593

Kharazishvili, Y., Kwilinski, A., Grishnova, O., & Dzwigol, H. (2020). Social safety of society for developing countries to meet sustainable development standards: Indicators, level, strategic benchmarks (with calculations based on the case study of Ukraine). *Sustainability*, *12*(21), Article 8953. https://doi.org/10.3390/su12218953

Kharazishvili, Y., Kwilinski, A., Sukhodolia, O., Dzwigol, H., Bobro, D., & Kotowicz, J. (2021). The systemic approach for estimating and strategizing energy security: The case of Ukraine. *Energies*, *14*(8), Article 2126. https://doi.org/10.3390/en14082126

Kumbhakar, S. C., & Lovell, C. A. K. (2000). *Stochastic frontier analysis*. Cambridge University Press. https://doi.org/10.1017/CBO9781139174411

Kwilinski, A., Hnatyshyn, L., Prokopyshyn, O., & Trushkina, N. (2022a). Managing the logistic activities of agricultural enterprises under conditions of digital economy. *Virtual Economics*, 5(2), 43–70. https://doi.org/10.34021/ve.2022.05.02(3)

Kwilinski, A., Dalevska, N., & Dementyev, V.V. (2022b). Metatheoretical issues of the evolution of the international political economy. *Journal of Risk and Financial Management*, *15*(3), Article 124. https://doi.org/10.3390/jrfm15030124

Kwilinski, A., Rebilas, R., Lazarenko, D., Stezhko, N., & Dzwigol, H. (2023). The Impact of the COVID-19 pandemic on the evolution of investment markets in Central and Eastern Europe. *Forum Scientiae Oeconomia*, *11*(4), 157–186. https://doi.org/10.23762/FSO_VOL11_NO4_8

Kwilinski, A. (2024). Understanding the nonlinear effect of digital technology development on CO_2 reduction. *Sustainable Development*, *32*(5), 5797–5811. https://doi.org/10.1002/sd.2964

Kwilinski, A., Lyulyov, O., & Pimonenko, T. (2024). Green economic development and entrepreneurship transformation. *Entrepreneurial Business and Economics Review*, *12*(4), 157–175. https://doi.org/10.15678/EBER.2024.120409

Loukil, K. (2016). Foreign direct investment and technological innovation in developing countries. *Oradea Journal of Business and Economics*, *1*(2), 31–40. https://doi.org/10.47535/1991ojbe008

Mendoza, J. M. F., Gallego-Schmid, A., Velenturf, A. P. M., Jensen, P. D., & Ibarra, D. (2022). Circular economy business models and technology management strategies in the wind industry: Sustainability potential, industrial challenges and opportunities. *Renewable* & *Sustainable Energy Reviews*, *163*, Article 112523. https://doi.org/10.1016/j.rser.2022.112523

Mesagan, E. P., & Chidi, O. N. (2020). Energy consumption, capital investment and environmental degradation: The African experience. *Forum Scientiae Oeconomia*, *8*(1), 5–16. https://doi.org/10.23762/FSO_VOL8_NO1_1

Moskalenko, B., Lyulyov, O., & Pimonenko, T. (2022a). The investment attractiveness of countries: Coupling between core dimensions. *Forum Scientiae Oeconomia*, *10*(2), 153–172. https://doi.org/10.23762/FSO_VOL10_NO2_8

Moskalenko, B., Lyulyov, O., Pimonenko, T., & Kobushko, I. (2022b). Institutions' effect on a country's investment attractiveness within sustainable development. *Virtual Economics*, *5*(4), 50–64. https://doi.org/10.34021/ve.2022.05.04(3)

Novotná, M., Volek, T., Rost, M., & Vrchota, J. (2021). Impact of technology investment on firm's production efficiency factor in manufacturing. *Journal of Business Economics and Management*, *22*(1), 135–155. https://doi.org/10.3846/jbem.2020.13635

Organisation for Economic Co-operation and Development (2023). *Foreign direct investment statistics*: *Data*, *analysis and forecasts*. https://mneguidelines.oecd.org/statistics.htm

Omri, A. (2020). Technological innovation and sustainable development: Does the stage of development matter? *Environmental Impact Assessment Review*, *83*, Article 106398. https://doi.org/10.1016/j.eiar.2020.106398

Park, S., & Yang, J.-S. (2021). Relationships between capital flow and economic growth: A network analysis. *Journal of International Financial Markets*, *Institutions and Money*, *72*, Article 101345. https://doi.org/10.1016/j.intfin.2021.101345

Pillai, N. V. (2019). *Measuring energy efficiency*: *An application of stochastic frontier production function analysis to power sector in Kerala* (MPRA Paper No. 101944). University Library of Munich.

Pylaeva, I. S., Podshivalova, M. V., Alola, A. A., Podshivalov, D. V., & Demin, A. A. (2022). A new approach to identifying high-tech manufacturing SMEs with sustainable technological development: Empirical evidence. *Journal of Cleaner Production*, *363*, Article 132322. https://doi.org/10.1016/j.jclepro.2022.132322

Ramadan, M., Bou Zakhem, N., Baydoun, H., Daouk, A., Youssef, S., El Fawal, A., Elia, J., & Ashaal, A. (2023). Toward digital transformation and business model innovation: The nexus between leadership, organizational agility, and knowledge transfer. *Administrative Sciences*, *13*(8), Article 185. https://doi.org/10.3390/admsci13080185

Rodrigues, L. F., Oliveira, A., & Rodrigues, H. (2023). Technology management has a significant impact on digital transformation in the banking sector. *International Review of Economics* & *Finance*, *88*, 1375–1388. https://doi.org/10.1016/j.iref.2023.07.040

Shi, Y., Ramayah, T., Luo, H., Zhang, Y., & Wang, W. (2023). Analysing the current status, hotspots, and future trends of technology management: Using the WoS and Scopus database. *Heliyon*, *9*(9), Article e19922. https://doi.org/10.1016/j.heliyon.2023.e19922

Sivalogathasan, V., & Wu, X. (2014). The effect of foreign direct investment on innovation in South Asian emerging markets. *Global Business and Organizational Excellence*, *33*(3), 63–76. https://doi.org/10.1002/joe.21544

Sultana, N., & Turkina, E. (2020). Foreign direct investment, technological advancement, and absorptive capacity: A network analysis. *International Business Review*, *29*(2), Article 101668. https://doi.org/10.1016/j.ibusrev.2020.101668

Szczepańska-Woszczyna, K., & Gatnar, S. (2022). Key competences of research and development project managers in high technology sector. *Forum Scientiae Oeconomia*, *10*(3), 107–130. https://doi.org/10.23762/FSO_VOL10_NO3_6

Tarighi, S., & Shavvalpour, S. (2021). Technological development of E&P companies in developing countries: An integrative approach to define and prioritize customized elements of technological capability in EOR. *Resources Policy*, *72*, Article 102051. https://doi.org/10.1016/j.resourpol.2021.102051

Tello-Gamarra, J., & Fitz-Oliveira, M. (2023). Technological capability and performance in developing countries: A meta-analysis. *Journal of Engineering and Technology Management*, *68*, Article 101753. https://doi.org/10.1016/j.jengtecman.2023.101753

Trzeciak, M., Kopec, T. P., & Kwilinski, A. (2022). Constructs of project programme management supporting open innovation at the strategic level of the organization. *Journal of Open Innovation*: *Technology*, *Market*, *and Complexity*, *8*(1), Article 58. https://doi.org/10.3390/joitmc8010058

Vetrova, E., Doroshenko, S., Tihomirov, N., Khakimova, G., & Kakava, L. (2020). Model of investment decision-making in a small industrial enterprise. *Forum Scientiae Oeconomia*, *7*(4), 7–23. https://doi.org/10.23762/FSO_VOL7_NO4_1

Viglioni, M. T. D., Calegario, C. L. L., Aveline, C. E. S., Ferreira, M. P., Borini, F. M., & Bruhn, N. C. P. (2023). Effects of intellectual property rights on innovation and economic activity: A nonlinear perspective from Latin America. *Structural Change and Economic Dynamics*, *67*, 359–371. https://doi.org/10.1016/j.strueco.2023.09.001

Walz, U. (1997). Innovation, foreign direct investment and growth. *Economica*, *64*(253), 63–79. https://doi.org/10.1111/1468-0335.00064

Wang, C., Liu, T., & Wang, J. (2021). The influence of outward foreign direct investment on enterprise technological innovation. *Mathematical Problems in Engineering*, *2021*, Article 6697298. https://doi.org/10.1155/2021/6697298

Wonglimpiyarat, J. (2019). What is it about strategic implications of using financial models in the process of technology management? *The Journal of High Technology Management Research*, *30*(1), 82–90. https://doi.org/10.1016/j.hitech.2018.12.001

World Bank (n.d.). *World Development Indicators*. https://databank.worldbank.org/source/world-development-indicators#

World Intellectual Property Organization (2023). *Global Innovation Index (2023)*. https://www.wipo.int/en/web/global-innovation-index/2023/index#:~:text=Photos%20on%20Flickr-,Which%20are%20the%20most%20innovative%20economies%20in%202023%3F,Global%20Innovation%20Index%202023%20rankings.

Xiao, N., Zhou, J., & Fang, X. (2023). Role of digital finance, investment, and trade in technological progress. *Global Finance Journal*, *57*, Article 100853. https://doi.org/10.1016/j.gfj.2023.100853

Ziabina, Y., & Dzwigol-Barosz, M. (2022). A country's green brand and the social responsibility of business. *Virtual Economics*, *5*(3), 31–49. https://doi.org/10.34021/ve.2022.05.03(2)

Zhang, W., Zhang, T., Li, H., & Zhang, H. (2022). Dynamic spillover capacity of R&D and digital investments in China's manufacturing industry under long-term technological progress based on the industry chain perspective. *Technology in Society*, *71*, Article 102129. https://doi.org/10.1016/j.techsoc.2022.102129

Zhou, W., Xu, Y., Zhang, L., & Lin, H. (2023). Does public behavior and research development matters for economic growth in SMEs: Evidence from Chinese listed firms. *Economic Analysis and Policy*, *79*, 107–119. https://doi.org/10.1016/j.eap.2023.06.005