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Technologization and Economic Transformation: The Influence of Technology Adoption in Reducing the Shadow Economy and Increasing Welfare

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ABSTRACT

In the context of technological discoveries, this study analyses the level and influence of the Technological Achievement Index (TAI) over the shadow economy and citizens welfare from thirty nations, in the time frame 2007 - 2022. The scientific community is very interested in the relation between technology and economic and social development. However, the precise impact that TAI has on other suitable indicators it's not yet well understood. Three linear regressions are performed following the update of the TAI values and the trends of the variables are compared. Findings show a correlation between a larger TAI and a growth of the Gross Domestic Product (GDP), a growth of the Human Development Index (HDI), and a contraction of the Shadow Economy. Results suggest that technology adoption can lead to positive social and economic consequences. As a result, this study provides relevant information for social and economic policies, highlighting the importance of technology investment to promote economic growth and diminish the shadow economy.

1. Introduction

The current era of rapid technical advances is unlike any other in human history. These innovations transform the institutions of human society in addition to impacting the way individuals live and work. Recent breakthroughs in artificial intelligence and renewable energy are profoundly changing the way we interact with the environment. Some of the most important problems facing humanity could be solved by these inventions, including expanding educational opportunities worldwide, improving access to healthcare, and last but not least, improving the economic climate (Hill & Dhanda, 2003).

The idea that technology promotes productivity and entrepreneurship, thereby fostering economic progress and well-being, is supported by the work of Gultom et al. (2024). Digital platforms and e-commerce have facilitated the access of individuals and businesses to various markets, reducing traditional barriers and accessing economic opportunities (Munteanu et al., 2023). In addition to these financial advantages, technological advances offer promising means of combating the underground economy. Governments and businesses can work together to prevent tax evasion and illegal trade by using technologies that improve transparency and provide access to sophisticated analytics and digital payment systems (Ván et all, 2022; Aivaz, Florea & Munteanu, 2024). Ultimately, this will lead to a more stable and fairer economic environment.

Relevant parameters must be examined to assess a country's development and well-being in order to fully understand the effects of these changes. The Human Development Index (HDI) combines information on life expectancy, income and education to create a complete picture of the general well-being of the population and is a good measure to track. The HDI is a useful tool for assessing access to opportunities and quality of life. Gross domestic product (GDP) calculates the entire value of goods and services generated in a nation over a given period. This is also another significant statistic. GDP is considered an indicator of a country's economic health because it shows how well equipped the country is to create economic prosperity and raise the standard of living of its population. However, since GDP does not consider general welfare or income distribution, it should be studied together with other indicators, including the HDI.

To paint a clear picture of the effects of technology on the economy and general well-being of the population, we will examine the intertwining of TAI, GDP, and HDI in this article. In addition, it will examine the theory that increased use of technology could improve economic activity and reduce the shadow economy,

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improving people's quality of life in real terms. Technology can transform education, health and infrastructure, contributing to a prosperous and equitable future for all nations.

2. Literature review

A groundbreaking article that attempted to quantify a nation's level of technology was published in the early 21st century. According to Desai (2002), there have long been pronounced differences in the degree of development of different countries in the creation and use of technology. It is therefore likely to become an increasingly important factor in determining global patterns of development and poverty in the 21st century. In the last decade, technological transformations and the emergence of the global market have increased the interest of nations to be connected to technology. This implies the presence of a capacity to develop and adapt to the use of technological innovations worldwide (Aivaz et Tofan, 2022). All nations face the challenge of participating and competing in the technology-driven global marketplace and ensuring that technology is used as a tool for human development. Consequently, Desai's (2002) article presents a measurement method for assessing a nation's technological progress to help policy makers determine the best and most important measures to implement for the welfare of society. The author created an index of technological achievements of a country. The Technological Achievement Index (TAI) represents the degree to which a country has adopted technological innovations, also creating a ranking of countries. The scientific community adopted this indicator, continuing the research over time of the technologization phenomenon. Studies such as Nasir et al (2011) and Burinskiene (2013) state that the level of technological readiness of a nation to participate in the global knowledge-based economy is known as technological achievements. Thus, a combination of suitable indicators is considered. While some indicators may provide insight into the current level of technological capability, other indicators may provide evidence that this capability is active and productive (Munteanu et al., 2024). A realistic picture of a nation's technological progress can be obtained by an adequate interplay of the two aspects.

The TAI index is a composite indicator that brings together the technological capabilities and performance of nations in four different categories: the development of new technologies, the diffusion of new technologies, the diffusion of old technologies and, finally, the development of human skills (Márquez-Ramos & Martínez- Zarzoso, 2010). This is an index with a rather accessible and elegant methodology, but useful and effective to assess the technological capacity of a country. The sub-indicators used in the calculation of TAI are considered to capture almost every aspect of technological achievements. Therefore, the TAI index is useful in assessing the relative technological readiness of countries to participate in the world economy.

The works of İncekara et al. (2017) and Ağan (2022a) complete the scientific literature. While the TAI assesses the technological performance of countries and ranks countries according to their technological achievements, it does not measure the extent of the country's technological development globally. It focuses on the technological performance of nations based on their ability to develop and use these technologies. At the same time, a nation can innovate under current conditions, but must accelerate technological diffusion in order to benefit from the fruits of labour in this direction. Countries should increase their technology acquisition capabilities if they want to enable the rapid diffusion of innovations and new technological breakthroughs (Ağan, 2022a).

The indicators correlated with the TAI level are the shadow economy, HDI and GDP. The underground economy is a well-known concept these days. It is a combination of tax evasion, corruption, undeclared work, among other illegal activities. Any legal, market-based production of products and services that is intentionally hidden from government agencies to evade regulation or taxation is included in the underground economy (Medina & Schneider, 2019, Koufopoulou et al., 2019). Quality of life is an evaluative term that results from the relationship between human desires, values and aspirations and the living conditions and activities that make up human life. It refers both to the global evaluation of life and to the evaluation of different conditions or spheres of life. This includes educational environment, work, health environment, interpersonal relationships, and family life (Bowling&Zahava, 2007; Florea, Aivaz & Vancea, 2023). The Human Development Index (HDI) is an index calculated based on life expectancy, years of schooling and GDP per capita. The closer it is to 1, the higher the level of quality of life. This index shows the maximum that a country's quality of life can have at a given time. According to the IMF (2024), GDP is important because it provides details not only about the size of an economy but also about its operational efficiency. An increase in GDP is generally considered an indication that the economy is doing well.

The gap in research, present in this field, is represented by the under exploration of the TAI index in terms of the composition and level of the indicator. The gap is also present in TAI's index relationships regarding other measurements relevant to the well-being of a nation. This paper wishes to address this gap by updating the level of TAI relative to EU member countries, but also to some countries with close relations with the European Union, and to analyse the nature of the relationship TAI index has with the shadow economy, HDI and GDP.

The objectives set out in this article are important in appreciating how technology relates to the economic and general well-being of a country. The first step is to calculate and review the TAI values for the nations under review. The updated hierarchy of the current technological status of these countries is a contribution to the scientific community. The second objective is to examine the links between TAI index, GDP, HDI and the shadow economy. A careful investigation of the interactions between these four parameters is necessary to accomplish this goal.

The first hypothesis states that there is a negative correlation between the shadow economy and higher levels of technology, indicated by higher values of the TAI indicator. This shows that technology can indeed provide ergonomic ways to reduce tax evasion and other illegal economic activities. According to the second hypothesis, there is a positive correlation between an increase in the HDI indicator and a higher value of the TAI indicator. This hypothesis indicates that with technological progress, life expectancy, wages and educational attainment also increase and lead to an overall improvement in the quality of life. The third hypothesis states that there is a positive relationship between TAI and GDP. This implies that technology encourages economic activity, which in turn leads to a strong and wealthy economy (Aivaz, 2021). By accomplishing these goals and examining proposed theories, the study hopes to shed light on how technology influences the nation's well-being and economy.

3. Method

The TAI indicator focuses on how the country participates in the creation and use of technology. According to the original methodology of Desai (2002), the composition of this index consists of eight sub-indicators that can be classified into four groups: the creation of new technologies, the diffusion of new technologies, the diffusion of old technologies and the development of human skills. The composition of the indicator was chosen considering two important aspects. First, the goal is to make this indicator as relevant as possible for a wide range of countries around the world, especially emerging countries with a low level of technological development. In these countries, a large part of the population still does not have access to "older" technologies such as the telephone, electricity, agricultural machinery and motorized transport. It is therefore necessary to include a variety of 'new' and 'old' technologies.

The creation of new technologies is relevant to all countries through innovation capacity. The ability to innovate using technology is dependent on the ability to create (Micu et al., 2021). In turn, this indicator is composed of two sub-indicators. The data series chosen to represent this indicator are “Patent granted to residents per million people” and “Receipts of royalty and license fees us$ per 1000 people”. Patents granted per capita measure a country's ability to innovate and create new technologies. Patents represent officially recognized innovations and inventions, protected by law, which reflect research and development activity in a country. A high number of patents per capita indicates a favourable environment for innovation and a high potential for technological progress. Revenue from foreign licenses and patents per capita shows a country's ability to capitalize on domestically developed innovations and technologies in international markets. License revenues reflect the global attractiveness and competitiveness of a country's technologies. It is a good indicator to assess how well a country can monetize its innovations.

Diffusion of new technologies represents a country's need to adopt technological innovations in order to benefit from possible new opportunities. Many high-tech sectors are among the most dynamic economic sectors in the world. When the technological content of the manufacturing sector improves, this diversifies the economy and opens opportunities in new markets. The Internet has incredible potential to increase political participation, population incomes, and health care by dramatically increasing access to information while simultaneously reducing costs. In turn, this indicator is composed of two sub-indicators. The data series chosen to represent this indicator are “Internet hosts per 1000 people” and “High- and medium- technology exports % of total goods exports”. The number of Internet hosts per capita indicates the degree of connectivity and access to modern communication technologies. This sub-indicator measures a country's digital infrastructure and ability to participate in the global digital economy. Medium and high technology exports as a percentage of total goods exports show the level of technological advancement of a country's industrial sector. Exports of advanced technologies indicate sophisticated production capacity and integration into global value chains. These data are representative of international technological competitiveness.

Diffusion of old technologies is necessary for technological progress to continue. Innovations must be widely disseminated. Old technologies are necessary for the use of new technologies and are present in many human activities. This indicator is composed of two sub-indicators, “Telephones (mainliners and cellular) per 1000 people” and “Electricity consumption (kw h per capita)”. The number of telephones (fixed and mobile) per capita is an indicator of the accessibility and use of basic communication technologies. Telephones are fundamental to social and economic connectivity, facilitating communication and access to information. This sub-indicator reflects a country's basic technological infrastructure. Electricity consumption measures the access and use of a technology fundamental to development. Electricity is necessary for almost all modern economic activities and for the well-being of the population. High electricity consumption indicates technological and economic development.

The development of human skills is a very important aspect. Technological dynamism requires critical mass of skills. Skills are needed for both creators and users of new technologies. It is necessary for a person to be able to manage a continuous flow of new ideas. The foundation of this skill is basic education for the development of cognitive skills and competence in mathematics and science. The indicator is composed of the sub-indicators “Mean years of schooling (age 15 and older)” and “Gross tertiary science enrolment ratio %”. A high level of education indicates a skilled workforce capable of innovating and adopting new technologies. This is a good indicator of the human capital required for technological progress. The gross enrolment rate in tertiary education in the sciences shows the number of students pursuing higher education in scientific and technical fields. A high rate indicates high research and development potential. It also reflects a country's commitment to training the specialists needed for technological advancement.

TAI does not have a fixed and regularly updated database that can be used. Therefore, starting in 2002, over the past 20 years, variations of the necessary sub-indicators have been used, depending on the availability of data at those times. Thus, the results obtained by each author show small variations. At the same time, depending on the availability of data and the objectives of scientific works, the TAI index was calculated, in most cases, for a single year and less for long periods of time. Sometimes, for sub-indicators with large gaps in data series, values from several consecutive years are used to obtain a relevant data series for the study over a one-year period (Desai 2002, Nasir et all 2011, Shahab 2015).

The TAI calculation consists of four main indicators divided into eight sub-indicators. According to the original document, for the construction of the TAI, each of the four indicators was given an equal weight of 25%. In turn, each sub-indicator has a weight equal to 50% of the representative indicator. Each of the four dimensions was assumed to play a similar role in classifying a nation's level of technological achievement. This study will follow the allocation made in the Desai (2002) article. In addition, in order for each variable in these dimensions to be at the same level, all the values of the sub-indicators were processed, through the min-max normalization method, using the formula in Equation 1.

Equation 1:

$$\text{Normalised Sub} - \text{indicators TAI} = \frac{(\text{CURRENT VALUE} - \text{MINIMUM OBSERVED VALUE}}{(\text{MAXIMUM OBSERVED VALUE} - \text{MINIMUM OBSERVED VALUE})}$$

Source: Desai (2002), Márquez-Ramos & Martínez-Zarzoso(2010), Nasir et all(2011), Incekara et all (2017), Ağan (2022a), Ağan (2022b)

The TAI index show, for each value, a numerical range between 0 and 1. Thus, the TAI index summarizes the technological progress of society and allows nations to achieve similar levels of innovation and technology. When a nation's index value is close to 1, it ranks ahead of those with a lower value. In case of gaps in the database, the linear interpolation method was used to estimate the missing values and complete the database, using the formula in Equation 2.

Equation 2:

$$\text{MISSING VALUE} = \text{VALUE FROM THE PREVIOUS YEAR} + \frac{(\text{VALUE FROM LAST YEAR} - \text{VALUE FROM FIRST YEAR})}{1 + \text{NUMBER OF YEARS WITH MISSING VALUE}}$$

Source: Ali (2017)

The case study is made according to the availability of values at the current time. The database for the calculation of the TAI index was created with the help of information obtained from appropriate sources such as Eurostat, the World Bank, the UNESCO Institute for Statistics and the World Intellectual Property Organization. The analysed countries are currently members of the EU, but also countries with close relations with the European Union, such as Great Britain, Switzerland and Norway. The period analysed is 2007-2022. In this study, the four indicators, which make up the TAI indicator, will have the following composition (Tab.1.) in agreement with the research of the specialized literature and the availability of the necessary data.

Table 1. The proposed composition of sub-indicators for the calculation of the TAI indicator

Indicators	**Used Sub-indicators**	
Creating new technologies	Total patent grants	Charges for the use of intellectual property, receipts (BoP, current US$)
Diffusion of new technologies	Individuals using the Internet (% of population)	High-technology exports (%)
Diffusion of old technologies	Fixed telephone subscriptions (per 100 people) + Mobile cellular subscriptions (per 100 people)	Final consumption - households - energy use - Gigawatt-hour
Development of human skills	Gross enrolment ratio, primary to tertiary, both sexes (%)	Scientific and technical journal articles

Source: Own processing based on the literary investigation carried out

In some cases, the chosen sub-indicators coincide with the original study (Fixed telephone subscriptions (per 100 people) + Mobile cellular subscriptions (per 100 people), Charges for the use of intellectual property, receipts (BoP, current US$), Total patent grants). The data on the Receipts of royalties and license fee sub-indicator were found under the name “Charges for the use of intellectual property, receipts (BoP, current US$)”. In some cases, the sub-indicators used show variations from the original study. Some of these can be found in later publications on TAI index calculation, such as Nasir et all (2011), Ali (2017), İncekara et all (2017) or Ağan (2022a) (Individuals using the Internet (%), Gross enrolment ratio - primary to tertiary, High-technology exports).

Other sub-indicators are different from those used so far but represent the same concept and can be used as proxies. Regarding the Electricity Consumption (kWh/capita) sub-indicator, obtaining the necessary data was not possible, so a substitute is used, namely “Final consumption - households – electric energy use - Gigawatt-hour / household”. At the same time, due to the much too large gaps in the data series, the second sub-indicator for the development of human skills was replaced by Scientific and technical journal articles. Articles in scientific and technical journals refer to the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, natural and space sciences. The main way researchers communicate their results to the wider scientific community is by publishing articles in scientific and technical journals. They present innovative research from various disciplines, from experimental studies to theoretical analyses. Essentially, these works encourage knowledge, cooperation and innovation, making them important for scientific and technological progress. Thus, articles in scientific and technical journals are a good benchmark for the innovation capacity of a population. Continuing to maintain the existing methodology in the specialized literature, the values obtained from the TAI index calculation will be divided into the following intervals (Tab.2.).

Table 2. The intervals related to the TAI index

Interval	Category	Colour
0,5 ≤ TAI	Leader	Blue
0,35 ≤ TAI < 0,5	Potential Leader	Green
0,20 ≤ TAI < 0,35	Dynamic Adopter	Yellow
TAI < 0,20	Marginalized	Red

Source: Own processing, Desai (2002)

The second part of the analysis was performed by applying three linear regressions. The data were arranged longitudinally for each of the 30 countries analysed over a 16-year period, allowing a consistent assessment of temporal variation. For each regression, TAI was considered as the independent variable, while the dependent variables were, in turn, the shadow economy, HDI and GDP. Regression coefficients, R^2 values and statistical significance tests were calculated, thus facilitating a detailed analysis of how TAI influences these economic and social variables.

4. Results

Following the methodology applied and the calculations performed, the following table resulted (Tab. 3). The table contains the calculated values of the TAI indicator, according to the original methodology, for the 30 nations under analysis, over an annual period from 2007 to 2022. The results have been coloured according to the intervals chosen (Tab.2) to better highlight the stage at which a nation is on the technology adoption side.

Table 3. TAI results, 2007-2022 and highlighting of results according to established intervals (Tab.2.)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Belgium	0.285	0.293	0.311	0.314	0.318	0.320	0.330	0.341	0.344	0.350	0.335	0.333	0.340	0.339	0.352	0.348
Bulgaria	0.131	0.146	0.160	0.164	0.172	0.183	0.190	0.188	0.189	0.190	0.191	0.192	0.192	0.190	0.194	0.192
Czechia	0.205	0.230	0.233	0.241	0.247	0.253	0.263	0.267	0.261	0.258	0.264	0.265	0.272	0.276	0.279	0.287
Denmark	0.305	0.305	0.313	0.298	0.315	0.322	0.327	0.329	0.329	0.318	0.309	0.310	0.311	0.311	0.320	0.330
Germany	0.565	0.578	0.574	0.565	0.558	0.564	0.598	0.614	0.614	0.627	0.635	0.647	0.661	0.657	0.737	0.746
Estonia	0.225	0.224	0.224	0.246	0.278	0.289	0.288	0.300	0.303	0.296	0.287	0.288	0.287	0.292	0.302	0.296
Ireland	0.289	0.285	0.277	0.281	0.304	0.308	0.316	0.321	0.336	0.349	0.340	0.354	0.340	0.351	0.375	0.436
Greece	0.207	0.236	0.258	0.245	0.253	0.266	0.262	0.270	0.292	0.304	0.309	0.312	0.320	0.323	0.329	0.350
Spain	0.296	0.305	0.321	0.342	0.355	0.362	0.360	0.371	0.372	0.377	0.383	0.390	0.397	0.404	0.425	0.459
France	0.478	0.499	0.505	0.528	0.526	0.558	0.560	0.557	0.563	0.569	0.566	0.571	0.577	0.566	0.592	0.562
Croatia	0.154	0.152	0.168	0.183	0.188	0.200	0.209	0.200	0.200	0.214	0.190	0.205	0.210	0.213	0.223	0.242
Italy	0.334	0.344	0.410	0.411	0.365	0.363	0.379	0.362	0.363	0.362	0.360	0.388	0.389	0.407	0.418	0.448
Cyprus	0.203	0.209	0.219	0.239	0.224	0.193	0.193	0.210	0.216	0.231	0.250	0.277	0.290	0.281	0.300	0.332
Latvia	0.174	0.182	0.185	0.185	0.192	0.213	0.232	0.235	0.254	0.260	0.262	0.259	0.254	0.262	0.263	0.259
Lithuania	0.220	0.235	0.239	0.244	0.247	0.252	0.240	0.236	0.238	0.246	0.260	0.247	0.243	0.243	0.251	0.257
Luxem.	0.215	0.214	0.229	0.236	0.240	0.235	0.240	0.236	0.239	0.235	0.233	0.231	0.230	0.231	0.240	0.137
Hungary	0.232	0.250	0.250	0.253	0.257	0.249	0.258	0.248	0.227	0.236	0.234	0.233	0.241	0.250	0.256	0.259
Malta	0.255	0.257	0.284	0.288	0.291	0.291	0.278	0.271	0.261	0.250	0.280	0.293	0.291	0.306	0.304	0.262
Netherl.	0.410	0.418	0.422	0.418	0.435	0.424	0.428	0.441	0.441	0.417	0.433	0.438	0.451	0.442	0.443	0.437
Austria	0.255	0.270	0.277	0.294	0.306	0.320	0.314	0.311	0.321	0.295	0.297	0.296	0.296	0.301	0.314	0.337
Poland	0.198	0.216	0.233	0.244	0.246	0.255	0.290	0.298	0.304	0.322	0.299	0.296	0.298	0.303	0.320	0.328
Portugal	0.208	0.215	0.198	0.210	0.216	0.222	0.227	0.232	0.236	0.239	0.247	0.252	0.260	0.267	0.283	0.292

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Romania	0.092	0.148	0.187	0.188	0.174	0.159	0.164	0.173	0.168	0.171	0.174	0.187	0.195	0.204	0.213	0.215
Slovenia	0.184	0.194	0.202	0.211	0.205	0.210	0.227	0.222	0.224	0.231	0.236	0.236	0.242	0.248	0.252	0.261
Slovakia	0.156	0.155	0.164	0.180	0.177	0.185	0.192	0.196	0.195	0.200	0.206	0.202	0.207	0.217	0.217	0.237
Finland	0.309	0.320	0.317	0.321	0.324	0.327	0.332	0.326	0.323	0.324	0.322	0.324	0.319	0.323	0.331	0.330
Sweden	0.324	0.331	0.338	0.346	0.344	0.345	0.382	0.380	0.385	0.381	0.386	0.377	0.380	0.383	0.387	0.381
Norway	0.311	0.314	0.319	0.328	0.326	0.324	0.323	0.325	0.326	0.331	0.329	0.325	0.328	0.322	0.332	0.346
Switzerl.	0.307	0.322	0.344	0.351	0.358	0.373	0.379	0.383	0.386	0.391	0.355	0.363	0.362	0.353	0.374	0.427
United Kingdom	0.504	0.503	0.516	0.529	0.524	0.525	0.551	0.547	0.551	0.568	0.554	0.552	0.562	0.580	0.603	0.631

Source: Own calculations of the TAI indicator based on the methodology presented and Desai (2002)

The obtained values of the TAI indicator as well as of the other indicators were processed in order to be able to analyse the trends of the four series of data relating to the period 2007 - 2022. The average of each indicator was calculated for each individual year. Afterwards, the obtained results were normalized using the min - max formula in Equation 1, to bring them into a comparable form. Thus, in the graph presented (Fig.1.), the evolution of the indicators can be observed and the existence of a degree of influence between them can be indicated.

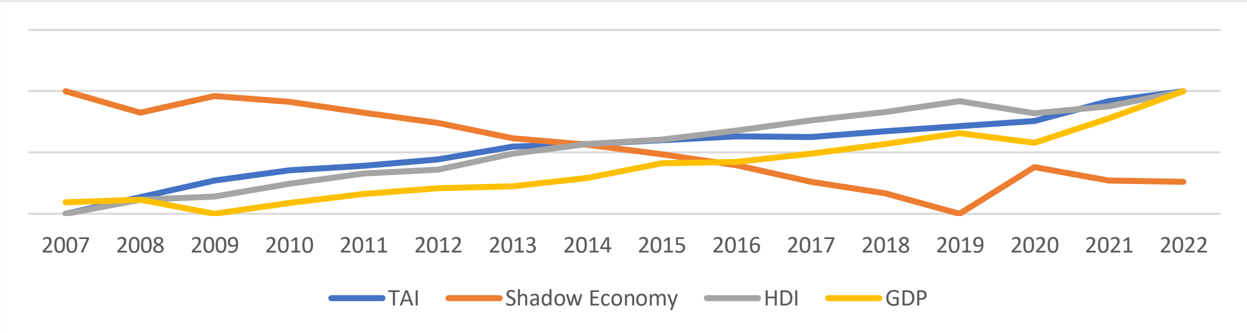

Figure 1. The trend of TAI, Shadow Economy, HDI and GDP in the period 2007 – 2022

Source: Own processing based on information found in Eurostat, https://hdr.undp.org/, European Parliament (2022)

After calculating the values of the TAI indicator, the results, along with the values for GDP, HDI and the Shadow Economy, passed through the filter of three linear regressions. By applying regressions, the study analysed the nature of the relationship between the chosen variables. The results of these regressions (Tab.4) co-confirmed the hypotheses proposed in the study. The Dickey-Fuller test was applied to assess the stationarity of economic data series. The Dickey-Fuller test is used to determine whether a data series has a unit root, that is, whether it is non-stationary and shows long-term trends. Testing for stationarity is important in econometrics to avoid spurious results in regressions or data analysis. A non-stationary series can lead to illusory causal relationships between variables. The obtained results validate that the series are suitable for econometric models, and the rejection of the null hypothesis at various levels of significance suggests that the data can be modelled and forecasted with a high degree of confidence.

Table 4. Summary of the results obtained after performing the three linear regressions

Regression	R-Squared	Adjusted R-Squared	Coefficient (TAI)	Standard Error (TAI)	t Stat (TAI)	P-value (TAI)	Significance F
TAI and Shadow Economy	0.3397	0.3383	-1.3744	0.0876	-15.6809	5.20263E-45	5.20263E-45
TAI and HDI	0.3902	0.3890	1.2148	0.0695	17.4901	2.62604E-53	2.62604E-53
TAI and GDP	0.8053	0.8049	1.5924	0.0358	44.4673	5.6909E-172	5.6909E-172

Source: Own processing based on data from Eurostat, https://hdr.undp.org/, European Parliament (2022) and own calculation of the TAI index via Microsoft Excel

5. Discussion

5.1. Observations based on calculated TAI index values

There are some aspects that can be observed based on the results obtained. Great Britain, France and Germany are positioned in the Leader category throughout the analysed period. These countries are followed by the Netherlands, Sweden, Switzerland, Italy and Spain in terms of performance, being in the Potential Leader category in most of the years under review. In the case of the countries that are positioned in the Dynamic Adapter category, the upward trend of the values can be observed. It should be noted that the countries Romania, Slovakia, Croatia and Latvia managed to overcome the Marginalized category and fall into the Dynamic Adapter category.

The annual classification obtained after calculating the TAI index, for the 30 mentioned countries, corresponds to the previous classifications existing in the specialized literature (Nasir et all 2011, Shahab 2015, İncekara et all 2017, Ağan 2022a). Variations between classifications are due to variations in the databases used by each author. France, the Netherlands, Germany or Great Britain are countries that consistently appear at the top of the rankings, while countries such as Bulgaria, Romania or Slovakia have consistently been at the bottom of the rankings but trying to catch up with more developed countries. As a general picture for the analysed period of 16 years, all the mentioned countries are in an extensive and continuous technological process, a fact demonstrated by the positive trend of the obtained values.

5.2. Observations based on data processing in graphic format

TAI index, HDI and GDP tend to evolve simultaneously in the same direction, while the shadow economy keeps its opposite direction. Thus, one can observe the beneficial connection between the degree of integration of technology in a country, the level of quality of life and the economic well-being of the population and the important role they play in combating the underground economy. Looking deeper into the analysis, differences in the degree of technology adoption between countries can be observed. Nations such as Germany show a steady increase in the TAI index over the years, indicating significant technological improvements. In contrast, countries such as Bulgaria are experiencing more modest growth, reflecting slower technological development. These trends highlight the disparity in technological progress between nations at different stages of development.

The percentage of the shadow economy generally tends to decrease over the years, with some increases during times of crisis. For example, Germany shows a significant reduction of the shadow economy from 13.9% in 2007 to 8.80% in 2022. However, countries such as Bulgaria or Romania still have a high percentage of the shadow economy, although there is a gradual decrease. This trend suggests that technological progress and better governance can help reduce the informal economy. The HDI index generally shows improvements over the years. For example, the index value for Germany increases from 0.923 in 2007 to 0.950 in 2022, indicating better living conditions and development. Similarly, for Bulgaria, the index improves from 0.776 in 2007 to 0.799 in 2022, albeit at a slower and more volatile pace compared to Germany. These trends demonstrate the continuous improvement in the quality of human life in different nations over time, albeit at different rates depending on the respective country's stage of development. GDP shows a general upward trend, although it fluctuates due to economic conditions and differences in the growth rate. This depends on the country's degree of development. The GDP of countries such as Germany and France increased by 55% and 36% respectively in 2022 compared to 2007. The GDP of countries such as Bulgaria and Romania increased by 164% and 122% respectively during the same period. Thus, robust economic growth is evident.

The hypothesis that an increase in TAI index is associated with a decrease in the shadow economy and an increase in GDP and HDI is confirmed based on the data provided. As the TAI index increases, there is a corresponding decrease in the percentage of the shadow economy in most countries. Countries with a rising TAI index have an increase in GDP but also higher HDI scores, indicating beneficial development. This signifies the positive involvement of technology in society. Implicitly, the daily life of citizens is also improved by increasing well-being, quality of life and by decreasing the underground economy, along with the associated negative implications.

5.3. Observations based on linear regressions

The regression analysis further encourages the confirmation of the proposed hypothesis. The R-squared value between TAI and shadow economy indicates that 33.97% of the variation in shadow economy can be explained by TAI. The two variables may have an inversely proportional relationship, as shown by the negative coefficient for TAI index. This indicates that the shadow economy typically declines by 1.37% for every 1% increase in TAI. This result is confirmed by the very modest P value and the F significance value, which highlights the statistical significance of this association.

For the regression analysis between TAI and HDI, R squared implies that 39.02% of the variation in HDI is explained by TAI. The coefficient for TAI suggests a positive relationship between the two variables. As TAI increases by 1%, HDI also increases by 1.21%. This relationship is statistically significant as evidenced by the low P-value and F-significance. The result supports the theory that better human development outcomes result from increased technological integration.

Regarding TAI index and GDP, the regression analysis yielded an R-squared value of 0.8053. This is suggesting of the high explanatory power that TAI index has on GDP. The coefficient for TAI index also indicates a strong positive relationship between the variables. With an incredibly low P-value and F-value of significance, this link is statistically significant. GDP improves by 1.59% for every 1% increase in TAI. This lends credence to the theory that increased economic output is the result of increased technological adoption.

The hypothesis stipulated above was that an increase in the TAI index would lead to a decrease in the shadow economy and an increase in HDI and GDP. Regression analysis provides strong support for these hypotheses. A higher TAI index is associated with a smaller underground economy and higher HDI and GDP values, confirming that technology adoption plays a very important role in promoting economic and social outcomes. These findings reflect real-world observations where technology adoption leads to significant changes in economic and social landscapes. A higher TAI index indicates greater technology integration. This often translates into more efficient governance and business operations as well as reducing the underground economy. Technology improves sectors such as education, health or improving tax compliance to the state.

The ability of the TAI index to explain so much of GDP variation is noteworthy, underscoring the profound impact of technology on economic activity. GDP is a comprehensive measure that includes various sectors such as manufacturing, services and agriculture. The strong integration of technology in these industries is indicated by the high explanatory power of TAI. This is applicable in the real world, as an increasing number of economic activities - such as digital financial services, e-commerce and automated manufacturing processes - depend on technology. The increasing reliance on technology in economic activity reflects how ubiquitous technology has become both in our daily lives and in the engines of productivity and economic growth. This observation underscores the importance of investment in technology to drive economic development and competitiveness in the world market. At the same time, the digitization of the payment methods of fees and taxes facilitates their collection by the state and the provision of the necessary budget revenues. Thus, the regression analysis confirms that greater technology adoption is significantly associated with a reduction in the shadow economy and improvements in HDI and GDP.

6. Conclusions

The objectives of this case study were to investigate the nature of the influence of the TAI indicator on the economy, formal and informal, and on the well-being of the population in 30 countries over the period 2007-2022. The empirical study was carried out in two stages. The first stage consisted of calculating TAI values and comparing them with trends in the shadow economy, HDI and GDP. In the second part, three linear regressions were implemented to explore the relationship between TAI and the same three variables as mentioned before. The obtained results provide valuable information and highlight the beneficial role of technology in economic and social development.

The updated TAI ranking for the analysed countries is consistent with previous scientific works, thus confirming the validity and relevance of the methodology used. The resulting ranking shows that countries with higher technological performance, such as the United Kingdom, France and Germany, are at the top of the list, while countries with slower technological development, such as Bulgaria and Romania, continue to progress but lag.

According to the first hypothesis, an increase in TAI was found to be associated with a certain decrease in the shadow economy. This suggests that technological progress contributes to reducing illicit economic activities and improving economic transparency. It is suggested that a one-unit increase in TAI leads to a 1.3744-unit decrease in the shadow economy, highlighting the potential of technology to combat the underground economy and promote a fair and more robust economic environment.

Regarding the second hypothesis, the study demonstrated a positive relationship between TAI and HDI, indicating that technology is necessary to improve the quality of life. For each unit increase in TAI, there is an associated 1.2148 unit increase in HDI, showing that technological innovations contribute to increased life expectancy, education levels and incomes, leading to better societal development humanity.

The third hypothesis is confirmed by the results showing that an increase in TAI has a significant impact on GDP. Each additional unit of TAI can lead to an increase of 1.5924 units in GDP, which shows that technology stimulates economic activities and increases productivity. This underlines the importance of technological integration in different economic sectors to stimulate economic growth.

The updated TAI ranking and detailed analysis of the relationship between technology, shadow economy, HDI and GDP provide valuable information for economic and social policies. Although this study contributes to the understanding of the role of technology in economic and social development, in terms of research gaps, further studies are needed to fully understand the interpenetration of technology in human society. The limitations identified for the study of the TAI index consist of the lack of consistency and stability regarding the data of the sub-indicators required for the calculation. The results show that technology adoption not only has the power to transform economies, but also helps create more prosperous and fair societies. These findings underscore the importance of continued investment in technology to drive economic development and population well-being, as well as continued investment in the study of such an indicator.

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Appendix

Table. A1. Sub-indicators used in TAI calculation in previous scientific works

Title	Author	Sub-indicators used	
Creating new technologies	Desai (2002)	Patent granted to residents per million people	Receipts of royalty and license fees us$ per 1000 people
	Nasir et all(2011)	Patents granted to residents (/million people)	Receipts of royalties and license fee (us$/person)
	Burinskiene (2013)	Patents granted per capital unit	Royalty and license fees received from abroad per capital unit.
	Shahab(2015)	Number of patents granted per capita	Receipts of royalties and license fees from abroad per capita
	Ali(2017)	Patents granted to residents	Receipts of Royalties and License fee
	Incekara et all (2017)	Patents granted per capita	Receipts of royalties and license fees from abroad per capita
	Ağan (Februarie 2022)	Patent grants by technology	Receipts of royalties and license fees
Diffusion of new technologies	Desai (2002)	Internet hosts per 1000 people	High- and medium- tehnology exports % of total goods exports
	Nasir et all (2011)	Internet users (/1000 people)	High-technology exports (%age of manufactured exports
	Burinskiene (2013)	Internet hosts per capital unit	High-technology & medium-technology exports as the percentage of all exports
	Shahab(2015)	Numbers of internet hosts per capita	High technology exports as a share of all exports
	Ali(2017)	Internet users (/100 people)	High-technology Exports
	Incekara et all (2017)	The internet users per 100 people	High technology exports as a share of all exports
	Ağan (Februarie 2022)	Internet hosts per 1000 people	Medium-and-high technology exports
Diffusion of old technologies	Desai (2002)	Telephones (mainliners and cellular) per 1000 people	Electricity consumption (kw h per capita)
	Nasir et all (2011)	Telephone mainlines + cellular subscribers (/1000 people)	Electric power consumption (kwh/capita)
	Burinskiene (2013)	Telephones (land line and cellular) per capital unit	Electricity consumption per capital unit
	Shahab(2015)	Telephones per capita (mainline and cellular)	Electricity consumption per capita
	Ali(2017)	Telephone + cellular Subscribers	Electric power Consumption
	Incekara et all (2017)	Telephones mainlines and cellular per 1000 people	Electricity consumption per capita (kw per capita)
	Ağan (Februarie 2022)	Telephones cellular and mainline (per 1000 people)	Electricity consumption (kwh/capita)
Development of human skills	Desai (2002)	Mean years of schooling (age 15 and older)	Gross tertiary science enrolment ratio %
	Nasir et all(2011)	Gross enrolment ratio at all levels, except pre-primary	Gross enrolment ratio in science, engineering, manufacturing and Construction (tertiary)
	Burinskiene (2013)	Average number of years of schooling	Gross enrolment ratio at the tertiary level in science, mathematics, and engineering
	Shahab(2015)	Mean years of schooling in the population aged 15 and above	Gross tertiary science enrolment, ratio
	Ali(2017)	Gross enrolment ratio primary to tertiary school, both sexes (%)	Gross enrolment Ratio in science
	Incekara et all (2017)	Mean years of schooling of the population age 15 and above	Gross tertiary science enrolment ratio
	Ağan (Februarie 2022)	Mean years of schooling received by people ages 15 and older	Gross enrolment in tertiary science

Source: Own processing based on the literary investigation carried out

Table A2. The periods for which the TAI has been calculated in previous scientific works

Author	Calculated period for TAI
Desai (2002)	1997-2000
Nasir et all(2011)	2009
Burinskiene (2013)	2010
Shahab(2015)	2015
Ali(2017)	1995 - 2015

Author	Calculated period for TAI
Incekara et all (2017)	2015
Ağan (2022)	1990 - 2019

Source: Own processing based on the literary investigation carried out

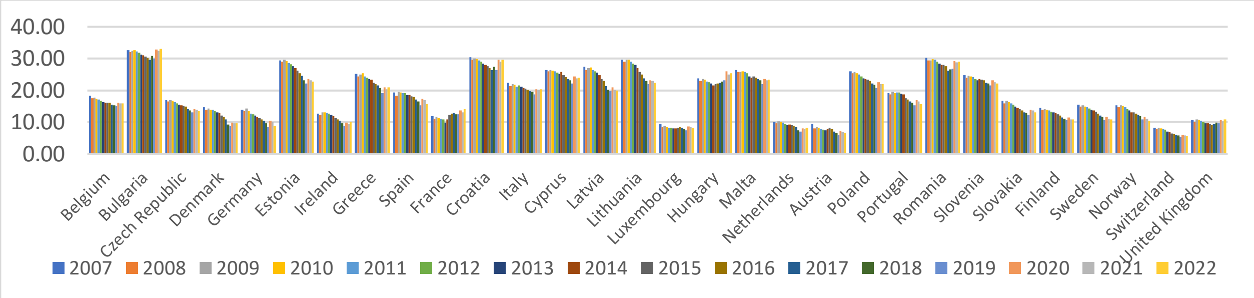

Figure A1. The trend of the Shadow Economy in the period 2007 – 2022

Source: own processing based on data from the European Parliament (2022)

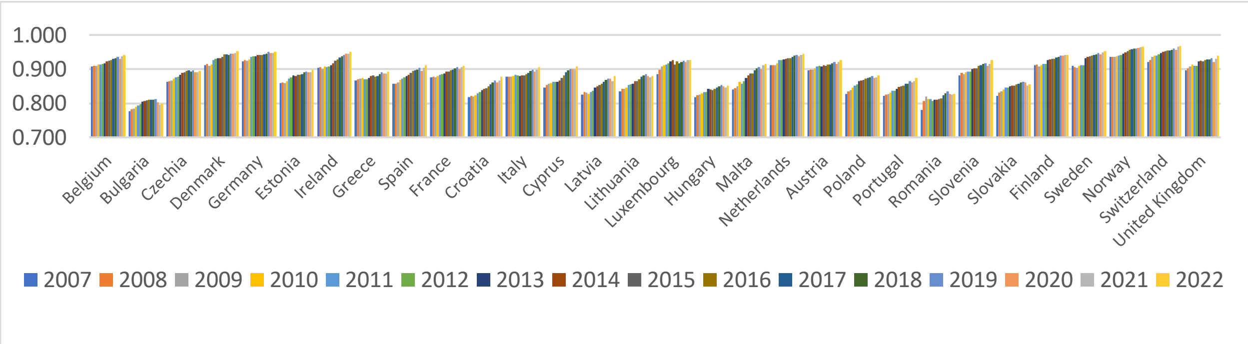

Figure A2. The trend of the HDI in the period 2007 – 2022

Source: own processing based on data from https://hdr.undp.org/

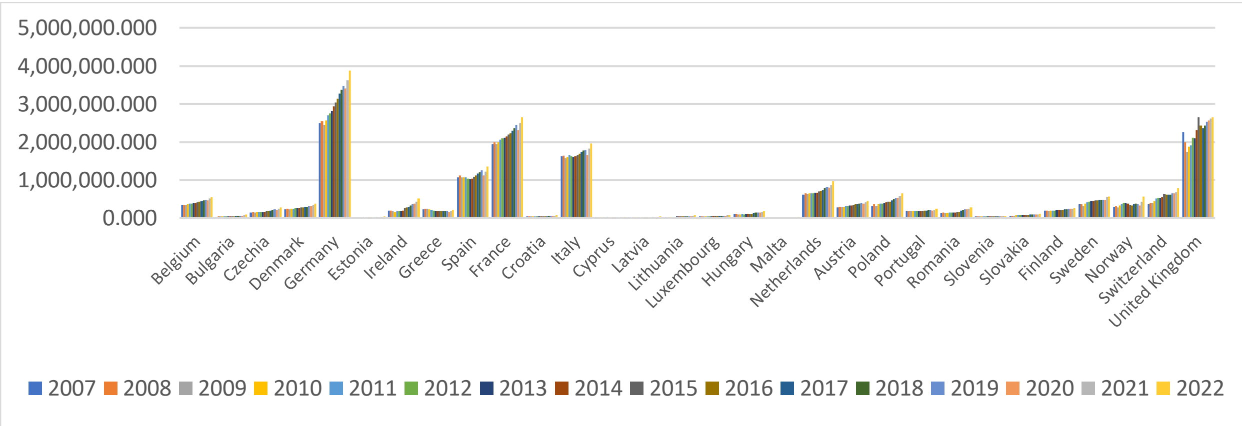

Figure A3. The trend of GDP in the period 2007 – 2022

Source: own processing based on Eurostat data

Table A3. Linear regression results TAI – Shadow Economy

Regression Statistics	
Multiple R	0.582819711
R Square	0.339678816
Adjusted R Square	0.338297391
Standard Error	0.21404769
Observations	480

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	11.26580477	11.26580477	245.8901483	5.20263E-45

Residual	478	21.90024578	0.045816414
Total	479	33.16605056	

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.876298034	0.028930071	30.29021373	2.7903E-113	0.819452202	0.933143867	0.819452202	0.933143867
TAI (independent variable X)	-1.374366538	0.087645981	-15.6808848	5.20263E-45	-1.546585569	-1.202147507	-1.546585569	-1.202147507

Source: Own processing via Microsoft Excel

Table A4. Linear regression results TAI – HDI

Regression Statistics	
Multiple R	0.62468543
R Square	0.39023188
Adjusted R Square	0.38895622
Standard Error	0.16962707
Observations	480

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	8.801896663	8.801896663	305.9045481	2.62604E-53
Residual	478	13.75365823	0.028773344		
Total	479	22.55555489			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.21577792	0.022926308	9.411804323	2.05901E-19	0.170729121	0.260826726	0.170729121	0.260826726
TAI (independent variable X)	1.21481346	0.069457097	17.49012716	2.62604E-53	1.078334482	1.351292437	1.078334482	1.351292437

Source: Own processing via Microsoft Excel

Table A5. Linear regression results TAI – GDB

Regression Statistics	
Multiple R	0.897397715
R Square	0.805322659
Adjusted R Square	0.804915385
Standard Error	0.087456207
Observations	480

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	15.12389618	15.12389618	1977.34482	5.6909E-172
Residual	478	3.656025141	0.007648588		
Total	479	18.77992132			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.361597036	0.01182033	-30.59111242	1.2317E-114	-0.384823266	-0.338370806	-0.384823266	-0.338370806
TAI (independent variable X)	1.592404169	0.035810641	44.46734554	5.6909E-172	1.522038433	1.662769905	1.522038433	1.662769905

Source: Own processing via Microsoft Excel

Table A6. Dickey Fuller test results

Model	**t-statistic Shadow Economy**	**t-statistic HDI**	**t-statistic GDP**
No Drift	-2.090	-1.471	-2.794
Drift	-3.962	-4.608	-3.635
Trend + Drift	-4.156	-4.730	-3.604
Augmented (2 delays)	-4.229	-4.260	-3.269

Source: Own processing via Microsoft Excel