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A SYSTEM OF INDICATORS FOR SELECTING INNOVATION TRIGGERS TO DRIVE SUSTAINABLE DEVELOPMENT

СИСТЕМА ІНДИКАТОРІВ ВИБОРУ ІННОВАЦІЙНИХ ТРИГЕРІВ ДЛЯ СПРИЯННЯ СТАЛОМУ РОЗВИТКУ

Summary. The foundation of sustainable development lies in innovation, technology, and entrepreneurship, which have significant positive impacts on socio-economic aspects of life. This study examines the indicators necessary for selecting innovation triggers that can lead country's sustainable development. Innovation trigger system is mechanism that initiates and drives the development of new technologies and processes, essential for sustainable development by facilitating the transition to more sustainable practices. However, not all innovation triggers succeed or offer long-term benefits for sustainable development. This study aims to identify the indicators necessary to select effective innovation trigger for sustainable country development. It has been described hype cycle phases of main technologies in the 21-st century, and defines that there is no one duration of hype cycle phases for AI, IoT, AR and VR, blockchain technologies. It has been proposed the innovation trigger system indicators to select beneficial innovation trigger that divided into two groups, set of lagging indicators and set of leading indicators. Lagging indicators assess the effectiveness of past strategies and investments, while leading indicators provide insights into future performance and potential outcomes. By utilizing both types of indicators, a more balanced and comprehensive analysis can be achieved when selecting the most beneficial innovation trigger for a country's development. The final choice of innovation trigger in each country will ultimately depend on its prioritized development goals. Additionally, it has been applied and modified the Bass Model to forecast the diffusion of AI among industrial enterprises in Ukraine. The basic Bass model has been extended to include a developer influence coefficient, which accounts for the role of AI developers in technology diffusion. Understanding the processes of diffusion and the effectiveness of innovation triggers, as well as the phases of the hype cycle, provides guidance for policymakers, business structures, and enterprises in technology implementation and the use of innovation for development, which determines the sustainability of national economic progress.

Keywords: bass model, diffusion of innovation, forecast of innovation, hype cycle, technology, technological wave.

Анотація. Основою сталого розвитку національного господарства є інновації, технології та підприємництво, які мають значний позитивний вплив на соціально-економічні аспекти життя в країні. Система інноваційних тригерів, що складається з процесів продукування, тестування, дифузії інновацій, є механізмом, що ініціює та стимулює розвиток нових технологій і процесів, які є важливими для розвитку, сприяючи переходу до продуктивніших сталих практик національного господарства. Однак не всі інноваційні тригери є ефективними для імплементації в виробничі процеси національного господарства. Метою дослідження є визначення системи показників, необхідних для вибору ефективного інноваційного тригера для сприяння сталому розвитку. Описано фази hype-циклу основних технологій 21-го століття. Визначено, що тривалість фаз hype-циклу для штучного інтелекту, інтернету речей, доповненої та віртуальної реальності, блокчейн-технологій є різною. Запропоновано систему показників вибору ефективного інноваційного тригера, які поділяються на дві групи: набір показників, що відстають, та набір випереджаючих показників. Показники, що відстають, оцінюють ефективність минулих стратегій та інвестицій, тоді як випереджаючі показники надають уявлення про майбутню ефективність та потенційні результати впровадження інноваційних тригерів. Використання показників обох груп забезпечує збалансованіший аналіз у виборі інноваційного тригера для розвитку країни. Остаточний вибір інноваційного тригера в кожній країні залежить від пріоритетних цілей розвитку. Застосовано модифіковану модель Басса для прогнозування поширення штучного інтелекту серед промислових підприємств в Україні. До базової моделі Басса включено коефіцієнт впливу розробника, який враховує роль розробників штучного інтелекту в поширенні технологій. Розуміння процесів дифузії та ефективності інноваційних тригерів, фаз hype-циклу формує орієнтири політикам, бізнес-структурам, підприємствам у впровадженні технологій, використанні інновації для розвитку, що визначає сталість поступу національного господарства.

Ключові слова: дифузія інновацій, модель Баса, прогноз інновацій, сталий розвиток, технологія, технологічний уклад, hype цикл.

Problem statement. Sustainable development aims to meet the needs of the present without compromising the ability of future generations to meet their own needs [1]. It encompasses economic growth, social inclusion, and environmental protection. The foundation of sustainable development is innovation, technology, and entrepreneurship. New technologies and innovations positively impact socio-economic aspects of life, and entrepreneurship is a source of innovation. The relationship between innovation and sustainability has been widely discussed, with various researchers pointing out the necessity of creating systems that promote the diffusion and implementation of new technologies.

The idea of an "innovation trigger system" emerges as a strategic mechanism to identify, foster, and propagate technologies capable of accelerating sustainable practices. This system involves selecting key indicators, both lagging and leading, that can help determine the long-term viability and potential impact of an innovation on national sustainable development.

In this context, the present article seeks to explore the development of an innovation trigger system, focusing on forming indicators that guide the selection of innovation triggers specifically suited to enhance sustainability goals.

Analysis of recent research and publications. The limited interdependence between economic growth and sustainable development is emphasized in the research by Chaparro-Banegas N. et al. [2]. At the same time, the authors highlight that countries with higher levels of economic development invest more in institutional, educational, and research systems based on innovation to stimulate national development. Thus, the promotion of innovation is a key element in driving sustainable development.

Technological solutions are effective only when they are diffused, as argued by Coenen L. and other researchers [3]. The process of innovation diffusion is defined as such that “even after a new product, production process, or organizational form is developed, its economic and/or social significance still depends on its acceptance among potential customers” [4].

Rekers J. V. identifies local factors influencing the diffusion of innovations in the fields of theatrical activities and pharmaceutical vaccines. The author argues that the diffusion of innovations is not a rational process but depends on the social environment and the product's reputation and legitimacy, which are shaped by intermediary organizations. The specifics of the industry and the legal framework of local markets also play a significant role in this process [5].

The case study method used by Scherrer M. et al. shows that the diffusion of Industry 4.0 technologies into business activities is associated with the formation of a clear value proposition. The authors argue that the implementation of new technologies requires analysis and decomposition of the business model [6].

Rogers E. identifies the key factors that determine the diffusion of innovations, such as relative advantage, compatibility, complexity, trialability, and observability [7]. Keupp M. and other researchers support the claim regarding the positive impact of resource constraints on the production of radical innovations in manufacturing companies [8]. The study by Perera S. et al. highlights the potential for the diffusion of blockchain technology into the construction industry through investments and startup activity [9].

Christofi M. et al. focus on the factors and processes of value formation in technological innovations during mergers and acquisitions [10]. The research by Graebner et al. also focuses on mergers and acquisitions as a method of technological innovation diffusion [11].

Tidd J. contend that the adoption of an innovation hinges on the interplay between demand-side and supply-side factors. The researcher examines various models of innovation diffusion and argues different ways of their dissemination through communication, awareness, marketing processes, and understanding the value of innovation [12].

So innovation trigger system is mechanism that initiates and drives the development and implementation of new ideas, technologies, and processes. This system is important for achieving sustainable development goals as it facilitates the transition to more sustainable practices and solutions. Innovation trigger system is a framework or processes that catalyze the creation and adoption of innovative solutions [13].

But not all innovation trigger is successful and have potential for long term benefit for country sustainable development [14].

The purpose of the article is to form innovation triggers system indicators to drive sustainable development.

The research question addressed in this study is: What are indicators necessary to use to select innovation triggers for sustainable country development?

Materials and Methods. The paper uses structural analysis and synthesis to form innovation trigger system indicators system for achieving country's sustainable development.

The article is structured as follows. We begin with a discussion and analysis of the key issues of the hype cycle of innovation. The next section provides description of hype cycle phases of some technologies in the last decades of 20-th and 21-st centuries. Following, the lagging and leading indicators of innovation trigger system is developed to select innovation trigger for support country's sustainable development. Then adaptation of the Bass Model, incorporating a developer influence coefficient, to forecast the diffusion of AI among industrial enterprises in Ukraine is developed. The final section provides discussion and main findings of research.

Summary of the main research material. The hype cycle is a graphical representation developed by Gartner to illustrate the maturity, adoption, and social application of specific technologies [15-16]. It describes the typical progression of an innovation from initial excitement to eventual productivity [17-21]. The model reflects the phenomenon of overestimating the short-term impact of a transformative discovery on its long-term consequences.

The hype cycle constructs in coordinates of expectations and time (See Fig. 1). It consists of five phases. At the first stage, name "Innovation trigger" a potential technology breakthrough kicks things off. Early proof-of-concept stories and media interest trigger significant publicity. Often, no usable products exist and commercial viability is unproven. Basically, it's commonly termed a "technology trigger," wherein the announcement of technological advancements sparks sudden interest.

Second stage "Peak of inflated expectations" characterizes early publicity produces a number of success stories, often accompanied by scores of failures. Some companies take action; many do not.

Then at the third phase "Trough of disillusionment" interest wanes as experiments and implementations fail to deliver. Producers of the technology shake out or fail. Investments continue only if the surviving providers improve their products to the satisfaction of early adopters. Fourth stage "Slope of enlightenment" provides more instances of how the technology can benefit the enterprise start to crystallize and become more widely understood. Second- and third-generation products appear from technology providers. More enterprises fund pilots; conservative companies remain cautious. At the last phase "Plateau of productivity" mainstream adoption starts to take off. Criteria for assessing provider viability are more clearly defined. The technology's broad market applicability and relevance are clearly paying off.

Innovation triggers are events or developments that initiate new waves of technological advancement and drive economic and social change. In the last decades of 20-th century and in 21-st century several key innovation triggers have significantly impacted various industries and societies. These triggers often lead to the emergence of new technologies, products, and services that redefine markets and create new opportunities. Some of them are cloud computing, AI, Internet of Things (IoT), blockchain, quantum computing, CRISPR and gene editing technologies [22-23]. Examples of technologies in the hype cycle in the 21-st century are demonstrated at Table 1 with description for every phase.

Thus, there is no one duration of hype cycle phases for AI, IoT, AR and VR, blockchain technologies.

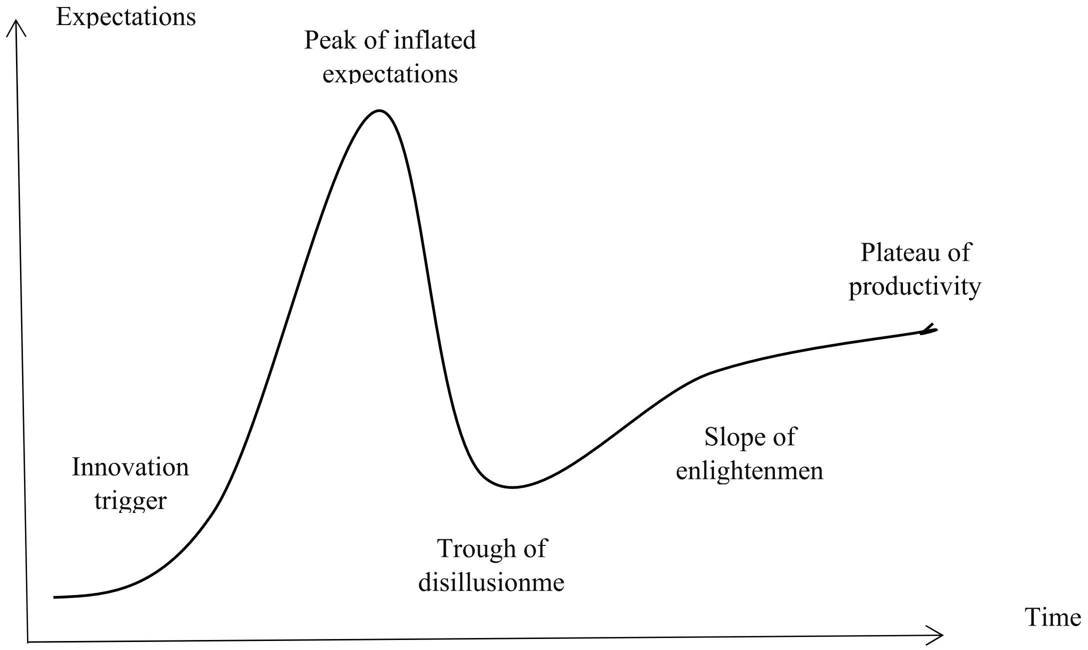

Figure 1 – The hype cycle of innovation

Source: [15]

Also it is important to notice that phase "Peak of inflated expectations" in 21-st century can be not too long (3-5 years).

Notably, it is risky and not easy process of selection and development some innovation trigger. It deals with many socio-economic factors. But still it is possible to form framework for work out with trigger selection.

We propose the innovation trigger system indicators to select beneficial innovation trigger. There is list of lagging and leading indicators that could be used to select it (See Table 2). Dividing the set of indicators into lagging and leading is important for several reasons. Lagging indicators provide information on what has already occurred. They are typically outcome-based and show the results of past activities. For example, the number of startups and total R&D expenditure reveal the level of innovation and investment that has historically taken place. Also these indicators help in evaluating the effectiveness of past strategies and investments.

Leading indicators offer insights into future performance and potential outcomes. They are often input-based and can signal changes that are likely to occur. For instance, the start-up success rate and the percentage of R&D as a portion of GDP can indicate the potential for future innovation and economic growth.

Using both types of indicators ensures a more balanced and comprehensive analysis in selection beneficial innovation trigger for country's development.

The final decision on selecting an innovation trigger using this set of indicators in each country will depend on the prioritized development goals (e.g., reducing carbon emissions or enhancing production efficiency) and the infrastructural capacity (existing or to be developed).

And next important question after innovation trigger selection (when it comes to other stage of hype cycle) is period of it diffusion in country's economy. We would like to present simple modelling of diffusion AI technology in Ukraine's industry.

Given the macro-level context of industrial AI diffusion in Ukraine the Bass Model is applied and adopted to estimate the diffusion of AI [32-34].

Initial Assumptions and Data:

(1) Number of industrial enterprises (NE): 102,500 (2022) [35]

(2) Number of AI developers (AD): 4,200 (2023) [36]

(3) Initial adopters: 500

(4) Coefficient of innovation (P): 0.01

(5) Coefficient of imitation (Q): 0.3

We add the developer influence coefficient (R), which accounts for the role of developers in technology diffusion. Let this coefficient be proportional to the number of developers, normalized to the number of industrial enterprises. Assume that each developer can influence 10 enterprises per year (I).

$$R = \frac{AD}{NE} * \mathrm{I} \quad (1)$$

R= 4,200/102,500×10≈0.41

(6) Coefficient of developer influence (R): 0.41

The formulas of the Bass model with an additional factor "Coefficient of developer influence, R":

(1) The proportion of new users at time t taking into account R:

Table 1 – Description of Hype Cycle Phases of Some Technologies in the 21-st Century

Phase	Period	Description
AI		
Innovation trigger	1970-1975	Early research and development in neural networks and machine learning algorithms
Peak of inflated expectations	1975-1985	Hype around AI's potential to transform industries, with breakthroughs in deep learning and successes like AlphaGo
Trough of disillusionment	1985-1995	Realization of the limitations of AI, challenges in data privacy, bias in algorithms, and high costs of implementation
Slope of enlightenment	1995-2005	Focus on practical applications in business analytics, automation, and customer service, with improved tools and frameworks
Plateau of productivity	2005-present	AI integrated into mainstream applications, driving efficiency and innovation across multiple sectors
Blockchain		
Innovation trigger	2008-2010	The creation of Bitcoin by Satoshi Nakamoto and the underlying blockchain technology
Peak of inflated expectations	2010-2017	Massive media attention and hype around Bitcoin and other cryptocurrencies, with Bitcoin reaching nearly $20,000 in December 2017
Trough of disillusionment	2017- present	Market correction, regulatory crackdowns, and numerous failed projects and scams leading to scepticism
Virtual reality (VR) and Augmented reality (AR)		
Innovation trigger	2010-2014	Early VR devices like the Oculus Rift and AR apps like Pokémon Go gaining attention
Peak of inflated expectations	2014-2017	High expectations for VR and AR to revolutionize gaming, entertainment, and business applications
Trough of disillusionment	2017-2019	Technical limitations, high costs, and lack of compelling content leading to decreased enthusiasm
Slope of enlightenment	2019- present	Focus on enterprise applications, training, and education, with improved hardware and software
IoT		
Innovation trigger	1999-2010	Conceptualization and early development of connected devices and sensors
Peak of inflated expectations	2010-2018	Predictions of billions of connected devices transforming homes, cities, and industries
Trough of disillusionment	2018-2021	Security concerns, interoperability issues, and unclear ROI leading to scepticism
Slope of enlightenment	2021- present	Development of standardized protocols and successful implementations in industrial IoT, healthcare, and smart cities

Source: created by authors based on [21; 23-31]

$$f(t)=\left(P+QF(t)+RF\right)t))\left(1-F(t)\right) \quad (2)$$

(2) Cumulative adoption (F (t)) taking into account R:

$$F(t)=\frac{1-e^{-(P+Q+R)t}}{1+\dfrac{Q+R}{P}e^{-(P+Q+R)t}} \quad (3)$$

Main figures of calculation present in Table 3.

So it seems more than 15-25 years is period for AI diffusion in Ukraine's industry (in the presence of all other necessary conditions (investments, infrastructure, etc.).

For a more accurate forecast for the following years, calculations should be continued, taking into account the data from the first two years and adjusting the model based on the actual dynamics of AI adoption among industrial enterprises in Ukraine.

Thus selecting and nurturing the right innovation triggers is advancement for sustainable development, demanding strategic investments and supportive policies. The integration of both lagging and leading indicators in this process enables countries to harness the full potential of technological advancements, driving long-term socio-economic growth and sustainability, reduced resource consumption, and lower CO^2 emissions [37], thus contributing to sustainable development.

Conclusions. The findings underscore the importance of a multifaceted approach to innovation diffusion.

The diffusion of innovations is based on a broad social context of their normative and cultural acceptance, provided there is a stable network of intermediaries. Some technologies are rejected or

Table 2 – Lagging and Leading Indicators of Innovation Trigger

Group of indicators	Lagging Indicator	Leading Indicator
1. Startup activity	Number of startups	
	Startup success rate	
2. R&D investment level	R&D expenditure	
		R&D as a percentage of GDP
3. Market metrics	Market size	
	Percentage of potential users or businesses adopting the new technology	
	Normalized volume of search queries in Google	
4. Scientific publications and citations	Number of publications	
	Citation index	
5. Venture capital funding (He Ni)	Total VC funding	
	Number of funding rounds	
6. Patents filling and grants	Number of patents	
	Number of patents granted, indicating successful innovations and legal protection	
7. Sustainable development		Decreasing CO2 emissions
		Less resources consumption, higher productivity

Source: created by authors based on [9; 18; 22]

Table 3 – Calculation of New AI Users among Industrial Enterprises in Ukraine

Year/Parameter	F	f	N
Year 1	0.0144	0.01993	2042
Year 2	0.0428	0.0387	3968

abandoned. For example, in the 1970s, the U.S. Army reduced research and development for defence against biological weapons. At the same time, the Soviet Union was creating the world's largest biological weapons program, and the invention of genetic engineering sparked what later became known as the biotechnology revolution.

There is set of indicators that could use foe selection of innovation trigger. As example, He Ni et al. demonstrate that venture capital has a positive but limited impact on the production of innovations in the Chinese market. The authors identify firm growth potential and government support as additional factors that determine the effectiveness of innovation creation by venture capital.

The analysis results allow us to conclude that innovation trigger initiate and promote the development and adoption of new ideas, technologies, and processes, are it is important for transitioning to more sustainable practices. However, not all innovation triggers are equally successful or beneficial in the long term. It is valuable to carefully select and support those that align with sustainable development goals.

The research identifies leading and lagging indicators groups that can guide the selection of effective innovation trigger. These include startup activity, R&D investment levels, market metrics, scientific publications and citations, venture capital funding, patent filings and grants, and sustainable development metrics. By leveraging these indicators, policymakers and businesses can better identify and foster innovation triggers that contribute to sustainable growth.

The diffusion of technologies like AI within a country's economy can be modelled to estimate the timeline and impact. For example, applying the Bass Model with a developer influence coefficient to AI diffusion in Ukraine's industry indicates a potential diffusion period of 15-25 years, given the necessary conditions such as investments and infrastructure.

To summarize, the effective selection and support of innovation trigger, guided by well-defined indicators and an understanding of the hype cycle, are necessary for achieving sustainable development.

While this study offers a framework for identifying and promoting innovation trigger to support sustainable development, several limitations should be acknowledged. The study’s analysis of lagging and leading indicators is essentially static, providing a snapshot based on available data at a given time.

However, the innovation landscape is dynamic and constantly evolving. Indicators that are relevant today may become less significant over time, and new indicators may emerge. A longitudinal approach, which tracks these indicators over time, would provide more nuanced insights. The role of cultural and social factors in the diffusion of innovation is not extensively covered in this study. These factors can significantly influence how new technologies are perceived and adopted. Future research should aim to address these limitations by incorporating more diverse datasets, refining modelling approaches, and considering a broader range of factors that influence innovation diffusion.

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