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A Conceptual Model for the Development of Transmodern Innovations

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Abstract

Innovation processes are strongly influenced by changes in economic, political, technological and other external factors. For instance, economic instability and political uncertainty can both stimulate and limit innovative activity in organisations. Transmodern innovation is a concept that involves scientific and technological advancements that may remain unutilised until favourable changes occur in technological or economic conditions. The purpose of this study is to develop a conceptual model for transmodern innovation that takes into account the dynamics of innovation, including the intensity, economic prerequisites, external changes and degree of innovation adaptation. This model will help organisations to better understand and respond to the complexities of the innovation process. The resulting model is a comprehensive tool for analysing changes in innovation activity and the external environment over different time phases, including the initial state (t0), the transition to new conditions (t1) and the final state (tx). In this model, the 'Final stage of tx' block represents the final stage, which allows us to draw conclusions about the success of adaptation and innovation development. This is the basis for formulating strategic conclusions and recommendations for future development.

Keywords: transmodern innovations, conceptual model, innovative activity, adaptation, time series

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Концептуальная Модель Развития Трансвременных Инноваций

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Аннотация

Инновационные процессы сильно зависят от изменений в экономических условиях, политической сфере, технологических новшествах и других аспектах внешней среды. Экономическая нестабильность, политическая неопределенность, а также технологические и социокультурные изменения могут как стимулировать, так и ограничивать инновационную активность организаций. Трансвременные инновации представляют собой концепцию, включающую научные и технологические достижения, которые могут оставаться неактуальными до тех пор, пока не наступят благоприятные изменения в технологических или экономических условиях. Целью данного исследования является создание концептуальной модели развития трансвременных инноваций с учетом различных аспектов динамики инновационных технологий, таких как интенсивность инноваций, экономические предпосылки, изменения внешней среды и степень адаптации инноваций. Полученная модель представляет собой комплексный инструмент для анализа изменений в инновационной активности и внешней среде на различных временных фазах, включая начальное состояние (t0), переход к новым условиям (t1) и конечное состояние (tx). В полученной модели блок «Конечное состояние tx» представляет собой завершающую фазу, которая позволяет сделать выводы об успешности адаптации и развитии инноваций, что является основой для формулирования стратегических выводов и рекомендаций для будущего развития.

Ключевые слова: трансвременные инновации, концептуальная модель, инновационная активность, адаптация, временные ряды

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1. Introduction

Adaptation to changing environmental conditions, particularly during economic crises or legislative changes, is essential for the survival and long-term success of organisations. In a rapidly changing environment, where innovation is key to maintaining competitiveness and promoting sustainable growth, understanding the factors that influence adaptation and innovation has become increasingly important. This process involves a thorough examination of the external factors that may impact the integration and implementation of innovative solutions across various sectors.

The purpose of this study is to develop a conceptual model that will allow us to evaluate and predict the dynamics of transmodern innovation through the analysis of interactions between economic, political, technological and socio-cultural factors. We aim to understand how innovations can adapt and evolve over time, considering both current and future economic, political and socio-cultural circumstances.

The focus of the research is on assessing innovative systems' ability to respond to external challenges through a time-series analysis. Developing a transmodern model would allow us not only to evaluate the current state and effectiveness of innovation activities but also to provide strategic recommendations for companies striving to enhance their competitiveness and market presence.

2. Literature Review

Trans-temporal innovation (TTI) is a category of innovative solutions, of various forms, formed in the period t_0, which remain in the stage of delayed relevance until the period t_x, characterised by the anamorphosis of environmental factors that form the economic prerequisites for their development (Urbinati, 2022).

TTI properties:

Deferred Relevance (τ) – the period of time between the formation of an innovative solution I_i and its actualisation in the period t_x:

$$\tau\left(I_i\right) = t_x - t_0, \leq t_x \tag{1}$$

Environmental Readiness (A_t) – the ability of the external environment for a period of time tx to create the economic conditions for the implementation of an innovative solution I_i:

$$A_t\left(I_i,t\right) > A_t\left(I_i,t_0\right),\ t \geq t_x \tag{2}$$

The Power of Diffusion (Θ) – a measure of the speed and degree to which an innovative solution I_i is distributed in the relevant research and applied field:

$$\Theta\left(I_i,t\right) > \Theta\left(I_i,t_0\right),\ t \geq t_x \tag{3}$$

Market Awakening (M_a) – the growth of market demand and the level of potential economic feasibility of an innovative solution I_i:

$$M_a\left(I_i,t\right) \propto V\left(I_i,t\right),\ t \geq t_x \tag{4}$$

Environmental Provocateur (P_t) – an event or sequence of events that stimulate the actualisation of TTI:

$$P_t \rightarrow \left(A_t\left(I_i,\ t\right) \wedge \Theta\left(I_i,\ t\right) \wedge M_a\left(I_i,\ t\right)\right),\ \ t \approx t_x \tag{5}$$

So, we can conclude that transmodern innovations are formed within the framework of scientific research and innovative experiments, but their value and benefits are not realised until the onset of the tx

period, when changes in technological processes, accompanying scientific discoveries or the evolution of market and economic conditions allow these innovative solutions to achieve the economic feasibility of potential applications (Palfreyman, 2022; Marion, 2021; Koloskova, 2020).

A clear illustration of the transmodern nature of innovation is the neural network. Neural networks were developed in the last century but were limited by insufficient computer performance and insufficient amounts of data for their training. With the development of computing power, increased availability of large amounts of data and improved algorithms, neural networks have found wide application in areas such as machine learning, natural language processing and computer vision. In the modern technological order, neural networks are a powerful tool for solving complex problems and are one of the key technologies in the field of artificial intelligence and machine learning (MacMahon, 2019; Milling, 2002; Meissner, 2015).

Electric vehicles can also be considered as a good example of this. The initial prototypes and ideas were proposed by Thomas Davenport and Robert Davidson about 200 years ago. However, a lot of time passed before their mass production and popularisation, as the development faced technological limitations, such as capacity, battery performance and weak infrastructure of charging stations. At the moment, the electric vehicle market is growing and developing rapidly, especially in countries with high fuel prices (Žižlavský, 2013; Siguaw, 2006; Schoen, 2005).

Another example of a transmodern innovation is genomic sequencing. Initial genomic sequencing technologies were developed with the long-term goal of understanding the genetic information of organisms, but limitations in performance, cost and speed of analysis limited their use. With the development of technologies in bioinformatics, biochemistry, computing and DNA analysis methods, genomic sequencing has become faster, more accurate, affordable and scalable. This has allowed scientists and physicians to expand the scope of this innovation in practice, using it for the diagnoses of diseases, the study of genetic mechanisms, plant and animal breeding and other applied tasks (Elzinga, 2023; Giannopoulou, 2011).

The purpose of this study is to develop a conceptual model for the development of transmodern innovation, which will be used to analyse various aspects of the dynamics of the development of innovative technologies.

3. Materials and Methods

The methodology relies on general scientific methods, including analysis and synthesis, induction and deduction and the abstraction and systematisation of information. The study examines the process of the development of transmodern innovations through two time periods: the initial period t0, in which innovations are formed, and the future period tx, in which they find their relevance and development due to changes in the external environment.

The process of innovation transformation can be represented in the form of successive steps, each of which is described by a system of nonlinear equations that reflect the relationship between innovations and the conditions of their development.

As parameters for modelling the transformation process of transmodern innovations, one can distinguish the *intensity of innovation*, which is an It parameter that can be interpreted as a measure of the activity and effectiveness of innovation implementation at a certain point in time t. Many researchers have described this characteristic of the innovation process. Peter Drucker's works, in particular, emphasise the importance of a systematic search for innovative development opportunities and the generation of new solutions within the framework of enterprise competitiveness management, which largely correlates with an understanding of the intensity of innovation (Mohr, 2009). Everett Rogers's research includes tools for analysing the speed and mechanisms with which innovative solutions are integrated into public practice, which is mainly applicable to the concept of innovation intensity (Dibra, 2015). Thus, the intensity of innovation can be viewed from several points of view, such as the speed of creation

and implementation of innovations, their impact on the economic and social environment as well as the willingness and ability of the system to accept and adapt to these changes.

The state of economic prerequisites Et in the context of modelling the process of transmodern innovation refers to a set of conditions of the economic environment that affect the possibility and effectiveness of the development and implementation of innovations at a certain point in time t. This parameter can include a variety of factors, such as the level of economic development, the availability of financial resources, tax policy, inflation, interest rates, public investment in research and development as well as the general state and dynamics of the market. Robert Solow, in his model of economic growth, postulated the thesis that productivity gains and economic growth are more driven by technological innovations than by an increase in the number of production factors, which emphasises the importance of economic conditions that intensify the economic process and the contribution of innovative results to economic development. Paul Romer, in turn, argued that economic growth can be supported by investments in human capital and innovations aimed at increasing production efficiency and opening up new opportunities for growth. Thus, economic prerequisites play a significant role in the innovation process, since they not only determine the readiness and ability of the economy to generate and implement innovations, but also create conditions for their further development and commercialisation. In the context of transmodern innovation, changing these conditions over time provides information about the optimal time intervals for launching and promoting innovative solutions, and makes it possible to model potential difficulties or growth points associated with this process (Travassos, 2024).

The changing environmental conditions of St reflect the dynamics and intensity of changes in how environmental specifics evolve and influence the development and implementation of innovations. This parameter has been indirectly investigated in the works of many scientists. Michael Porter analysed the economic structure of the industry through the prism of the 'five forces', which can be considered the key elements of environmental change in the context of economic and strategic perspectives (Porter, 1995). John Cotter, within the framework of the 'eight steps' model of change management, defined the key role of the external environment in initiating and maintaining change processes in organisations. Ulrich Beck, in his concept of 'risk societies', argued the thesis that modern societies are characterised by increasing uncertainty and that the associated risks, as part of a changing external environment, require societies and organisations to develop innovative approaches and strategies for their reification (Prieger, 2007). Thus, changes in the external environment have deep significance within the framework of the transformation process of transmodern innovations, since they can both stimulate and restrain innovative activity, influencing the time frame and conditions under which innovations are actualised in science and practice (Dahlander, 2021).

The degree of adaptation of an innovation At reflects the ability and readiness of an innovative process or product to change or modify to meet fundamentally new or changing environmental conditions during time t. This parameter is important for understanding the labour intensity involved in adapting an innovative solution to new market requirements, technological standards, socio-cultural norms or environmental constraints. Everett Rogers, within the framework of the theory of diffusion of innovations, studied the processes by which innovations spread between participants in the social system, addressing the issue of adaptation as one of the factors influencing the success of innovation (Globe, 1973). Rogers also discussed how social, cultural and individual characteristics influence the acceptance and adaptation of innovations by society. Michael Tushman and Philip Anderson, within the framework of the concept of 'technological shifts', investigated how companies adapt to radical technological changes, focusing on the need to adapt management practices and organisational structures for the effective integration of new technologies (Sivarajah, 2024; Hekkert, 2007). Clyden Christensen, within the framework of the theory of 'disruptive innovation', described how new technologies that are initially created in niche markets can eventually radically change industries, displacing established companies (Damanpour, 2012). In Christensen's concept, adaptation to new conditions is a key element of the survival and sustainable development of companies (Chursin, 2016). Understanding and analysing the degree of adaptation of innovation is critical to assessing the viability and potential for the long-term development of innovations.

In the context of modelling transmodern innovations, At emphasises the need for a flexible approach to the development and implementation of innovative ideas (Seebode, 2012).

4. Results

The relationship of the proposed parameters can be described by the following system of equations:

$$\frac{dI}{dt} = f_1\left(E(t), A(t)\right) \tag{6}$$

$$\frac{dE}{dt} = g\left(S(t)\right) \tag{7}$$

$$\frac{dS}{dt} = h\left(t, S(t)\right) \tag{8}$$

$$\frac{dA}{dt} = k\left(I(t), S(t)\right) \tag{9}$$

Function f1 describes how changing economic prerequisites and the degree of adaptation of innovation affect its development. The deterioration of economic conditions may imply a number of scenarios – from macroeconomic instability to local financial crises – that can have a significant impact on the operation of enterprises, the investment climate, consumer sentiment and overall economic activity. These changes in the economic and political landscape can be caused by a variety of reasons. These include, for example, economic downturns, which lead to a decrease in total output and the number of jobs. Inflation also plays a role, increasing the price level and thereby reducing consumer opportunities. An increase in interest rates can complicate the process of obtaining loans for both individual consumers and corporations, which makes investment activity more difficult. Instability in the political arena can increase business risks and reduce investor confidence. Finally, global financial crises involving multiple countries can lead to consistent economic disruptions in different regions. The deterioration of economic conditions has a direct impact on innovation processes. In times of economic uncertainty, both companies and investors may show restraint in investing in new projects and developments, which leads to a reduction in investment in innovation activities. This fact changes consumer preferences, leading consumers to favour products and services that either satisfy basic needs or offer a relatively high value per unit cost. In response, companies are forced to adjust the supply structure, optimise operating costs and rethink innovative strategies to maintain competitiveness and, as a result, profitability. However, these uncertain conditions can also stimulate the innovation process, as enterprises are forced to look for alternative ways to survive and develop. In some cases, the crisis may additionally motivate companies to develop new products or optimise processes in order to achieve long-term development and increase sustainability.

The g-function mathematises how the dynamics of changes in the external environment interact with economic fundamentals, emphasising the complex impact of various factors on the economic state, which, in turn, directs the development of innovations. These factors cover global economic trends, including the growth or decline in gross domestic product (GDP) of the world's leading economies, which can expand or narrow international markets; political stability and changes in legislation that ensure the predictive ability of business; rapid changes in technologies that redefine industry standards; and socio-cultural changes affecting consumer preferences and behaviour. Environmental changes are also critically important, forcing companies to rethink production processes and market approaches. The logical and meaningful nature of the g-function allows us to form a deep understanding of how these changes shape the economic atmosphere by indirectly stimulating or constraining innovation activity. These variables can play a role in expanding new markets, accelerating investment activity, stimulating entrepreneurship and technological development, as well as in shaping new industrial dynamics.

The h-function provides a critical analysis of how variations in the external environment, including economic fluctuations, political instability and technological innovations, affect different systems over time. This function is characterised by potential nonlinearity, emphasising that even minor changes in bifurcation conditions can lead to significant and not always predictively significant effects within the system. The inclusion of time dynamics in the analysis allows one to track how changes affect the system over time, providing an understanding of both short-term and long-term consequences. Modelling these changes is critically important for organisations focused on strategic planning and risk management, as it allows them to prepare more effectively for future scenarios and optimally respond to emerging challenges, minimising the potential negative consequences of external destabilisation factors.

The k-function mathematically approximates the relationship between the intensity of innovation activity, including the development of new technologies, product improvement and innovative business practices, and changes in the external environment. These changes can range from economic fluctuations to socio-cultural trends, technological innovations as well as changes in policy and legislation. The interaction of these two elements impacts how effectively innovations can adapt to new external conditions. For example, a favourable external environment equipped with supportive legislation and technological advances can facilitate the application and dissemination of innovations. However, in the context of legislative barriers or an economic recession, even active innovation can face obstacles, which require innovators and companies to adapt more deeply and develop innovative strategies to overcome these obstacles.

Figure 1 shows a conceptual model for the development of transmodern innovation.

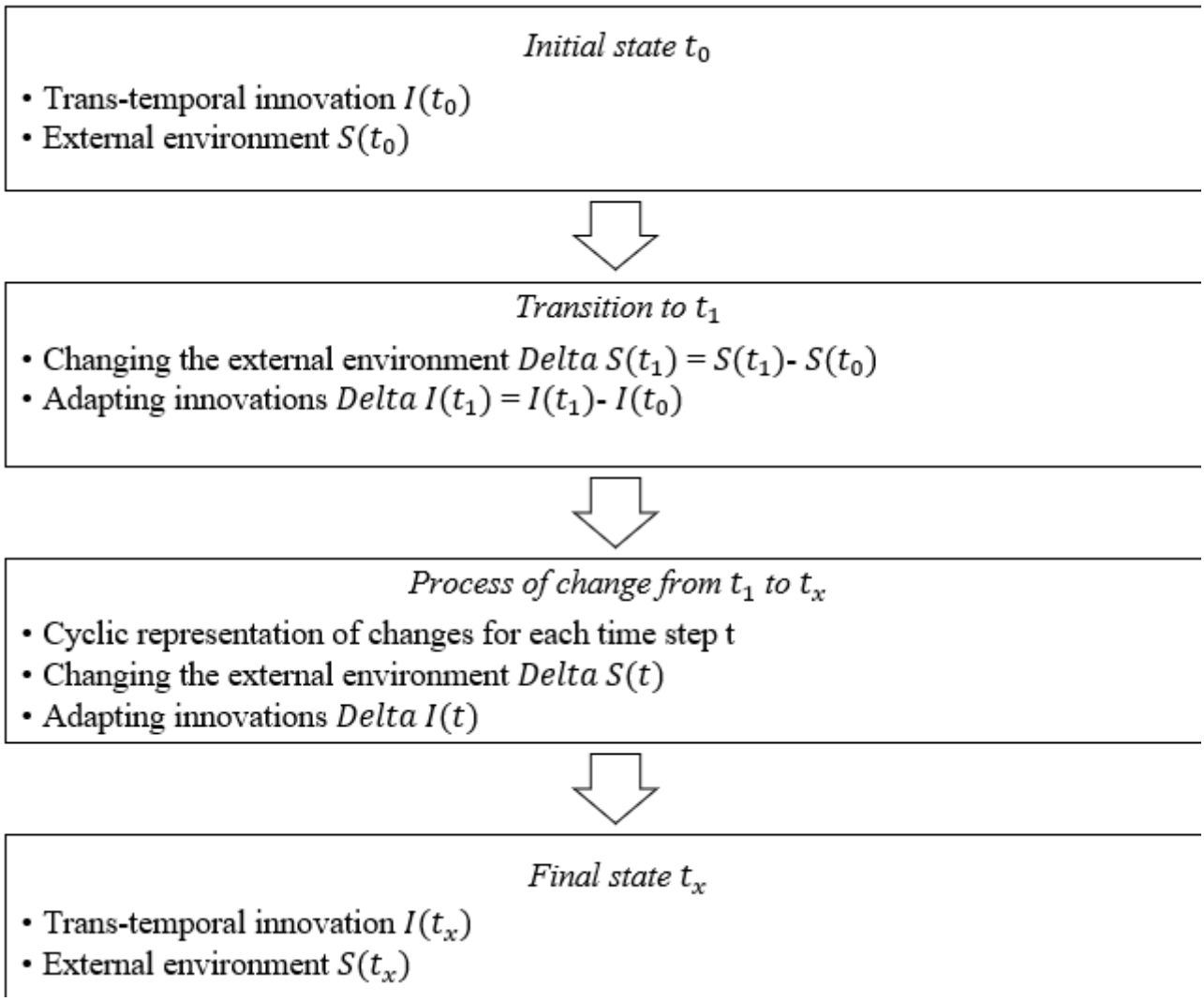

Figure 1. Conceptual model of the development of transmodern innovation.

The ‘Initial state t0’ block is the basis of the entire flowchart, which sets the initial parameters for the subsequent modelling of the properties of transmodern innovation and changes in the external environment. Within this block, the basic levels of innovation activity are established, which reflect the beginning of innovative processes, products or technologies. Also, the characteristics of the external environment at time t0 are determined, and the data are supplemented by taking into account political, economic and technological factors that approximate the context that can influence the further development and adaptation of innovative results. These initial parameters play a critical role in modelling the initial state and provide reference points for monitoring the dynamics of changes throughout the time period under consideration.

In the flowchart, the ‘Transition to t1’ block represents the initial stage of changes, within which there is an active interaction between innovations that have the property of duration in time and the changing external environment. This section focuses on two main aspects: the first comprises changes directly in the external environment, covering all the key economic, political, technological and social shifts that occurred earlier; the second is the adaptation of innovations, which may include processes such as the introduction of new technologies, the recycling of existing products or a change in strategic direction in response to new conditions and challenges of the time. This section illustrates how innovations begin to adapt to new external conditions, marking the initial stages of this transition process. In fact, this block is a significant analytical point for assessing how effectively the innovation system is able to respond to external challenges and adapt at the initial stage of this interaction.

The block ‘Process of change from to to tx’ plays a key role in the structure of the flowchart, covering the constant process of adaptation and transformation of transmodern innovations and environmental changes during the analysed time period. In this block, each time point is considered individually, which makes it possible to monitor recurring changes in the external environment and adaptation processes within the framework of innovation activities. Changes in the environment and how innovations respond to them are documented in each individual time interval. These adaptation processes may include the introduction of relevant technologies, strategic business reorientation or other forms of innovative activity aimed at increasing competitiveness and realising new opportunities. Each time period also includes an analysis of the impact of key political, economic and technological factors of development, which contributes to a deep understanding of how they form the context in which major changes occur. Thus, the block describes in detail the complex interaction between changing conditions and innovation activities, demonstrating the evolution and adaptation of business processes and approaches in a rapidly changing world and forming a pool of effective long-term development strategies.

The ‘Final state of tx’ block in the flowchart visualises the final phase of modelling, within which a summary of all transformations and adaptations that took place during the analysed time is presented. This block displays the final state of transmodern innovation and the external environment, allowing one to assess the impact of events that have occurred. It reflects the current state and nature of innovation activity, which demonstrates how successful the adaptation and development of the innovations have been. The analysis of the current state of the external environment is also carried out, which includes economic, political, socio-cultural and technological changes. Understanding the impact of significant events in the fields of politics, economics and technology allows us to determine their significance in the formed results of innovation activity and environmental conditions. This block is critically important for synthesising the results of the entire process, highlighting achievements and shortcomings in innovation management and allowing one to formulate strategic conclusions and recommendations for future development.

5. Discussion

The importance of the resulting model lies in its ability to provide insight into the nature of innovations over time and their potential application in various industries.

The conceptual model examines the evolution of innovation, paying attention to the interaction

of innovation processes with economic, political, technological and other changes in the environment. Changes in economic stability, the political environment, technological progress and socio-cultural aspects can both stimulate and inhibit the innovative activity of an organisation. This means that even active innovation can face obstacles, such as legislative barriers or economic downturns. Overcoming these obstacles requires deeper adaptation and innovative strategies.

In the context of studying the development of transmodern innovations, this model can be applied to track the progress of technological advances in different time periods, allowing researchers and practitioners to identify key points of innovation, technological shifts and their consequences. Moreover, it can become the basis for forecasting future technological trends and achievements, thereby supporting strategic decision-making in various industries.

Thus, the transmodern innovation development model is an important tool for evaluating and predicting the dynamics of innovative technologies to formulate strategic conclusions and recommendations for future development.

6. Conclusion

In this study, a conceptual model of the development of transmodern innovation was obtained, which can be applied to track the dynamics of technological innovations at different points in time, in particular, from t_0 to t_x. It can serve as a basis for understanding how innovations evolve and transform from t_0 to t_x, potentially shedding light on patterns, breakthroughs and disruptions in technological development. The mathematical functions f_1, g, h and k represent a complex interaction of economic, political, technological and socio-cultural factors and allow us to analyse how changes in economic prerequisites, the external environment as well as political and technological innovations affect innovation processes at various time stages.

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