System dynamics modelling to study the impact of digital technologies on regional development

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***Abstract*— The use of Smart Technologies in Regional Innovation Systems (RIS) for Regional Development is the main topic of this study. A dynamic model has been created that depicts the contribution of smart technologies to the factors of a Regional Innovation System. In this paper we analyse the first three out of five stages of system dynamics structure approach, namely we start by identifying the problem recognition, we move on to the description of the system and we conclude with the qualitative analysis which demonstrates the causal-loop diagram of the Regional Innovation System.**

Keywords—component; smart specialisation; smart technologies; regional innovation systems; regional development; system dynamics

I. Introduction

This research comes to study the use of New Technologies in Regional Innovation Systems for Regional Development. To do this a dynamic model is created, that captures the level of Regional Development in relation to the contribution of smart technologies to the actors involved in the Regional Innovation System. This model will serve as a guide - methodological tool - for the formulation of the appropriate regional policies, as it will allow the identification of strengths and weaknesses within the Regional System, enhancing those that cause multiplier benefits at the level of Regional Development.

Regions constitute a major actor in the global economy, as they are the first to be affected by economic change and are therefore actively involved in research and innovation policy-making. The Regional Innovation System (RIS) is a key background for the implementation of these policies as well as for the analysis of the innovation process at regional level. Understanding the dynamics of the RIS has piqued the interest of economic geographers, regional science academics and regional policy makers since the early 1990s [1-4]. A RIS is perceived as a network of public and private actors, institutions and organizations whose activities and interactions create local channels for the utilization, development and dissemination of available skills, technologies, capabilities and resources. Three important points need to be clarified for the Regional Innovation System: firstly, it is mainly a social system, secondly it encloses the systemic interaction between economic actors (private or public sector) and thirdly, this interaction aims to enhance local knowledge and learning [5].

Along with the interest in regional innovation systems and smart specialization, another theme and policy today identifies urban and regional development, that of Smart Cities. According to the literature, globally, the smart city is the basis for the sustainable development of urban centers and ensures their future expansion in terms of sustainability and development based on knowledge and digital technology (smart growth). Smart cities are part of the larger plan of western societies for access to society and the knowledge economy. They describe environments that enhance human capacity for creativity, learning and innovation. They are created by merging local innovation systems operating within cities (such as innovation poles, technology districts,

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technology parks, clusters) with digital networks and information society applications. Their ability to combine three forms of intelligence: the human population of cities, the collective of innovation institutions, and the artificial of digital networks and applications, is where their value lies.

From the extensive literature review we conducted in the above two literature reports, in this study we will investigate how the two literature and policies are related, (a) the regional system of innovation and smart specialization and (b) smart cities, and how in common they contribute to a dynamic development at regional level. More specifically, we noticed gaps in the connection of these bibliographic references, which the present research tries to fill. In addition, the literature review revealed that there is no proper approach to the design and implementation of the smart specialization strategy (RIS3).

To bridge this gap in strategy development, skills and methods, the literature suggests the use of Smart Technologies. Intelligence, in terms of innovation, collaboration and coordination, can be effectively developed through networking [6]. For this purpose, the use of online platforms in policy making and strategic planning could be considered as a key component of the Regional Innovation System [7].

The use of Smart Technologies in Regional Innovation Systems with the aim of Regional Development, is studied in this research. To do this we created a dynamic model at the regional level, with the use of system dynamics, that captures the contribution of smart technologies to the factors that shape a RIS. It's worth noting that there are at least two arguments in favor of a systematic approach to RIS analysis [8]. To begin with, each RIS has its unique set of features. Second, in order to anticipate how a RIS will evolve, it is important to provide a dynamic description of its setup. As previously stated, this approach indicates that RISs are made up of numerous actors (variables), each of whom is related to the creation of change patterns in each system through their own rate and direction of change.

The research is characterised by scientific originality as the extensive literature review within the RIS revealed that there weren't many studies describing the contribution of new technologies to the shaping of smart specialization strategy. Moreover, the contributions that has been identified, remains only at a descriptive analysis level. Therefore, in the first place, this research covers the gaps identified in the literature with regard to the contribution of new technologies to regional development. Secondly, the use of system dynamics theory is another scientific originality as it enables the development of scenarios to improve regional development with the help of simulation.

II. METHODOLOGY

This research is based on a one-and-a-half-year professional researcher project for researchers with an emphasis on young researchers - cycle B ', under the auspices of the Operational Program for Human Resources Development, Training and Lifelong Learning 2014-2020.

The research team in order to answer the questions of the present research divided the study into four phases. The first concerns the in-depth analysis of the variables (a) of Smart Technologies, (b) of Regional Innovation Systems and (c) of Regional Development description. An in-depth analysis of the three concepts was performed, as well as the variables that can be used to capture them. In addition, extensive article research was conducted to capture the actors involved in the Regional Innovation System, as well as to capture the interactions between them. The second phase concerned the collection of data through databases, published statistics and extensive articles. The sources used are both the most widely known and publicly accessible databases such as the European Statistical Office (Eurostat), the World Bank, and the Organization for Economic Co-operation and Development (OECD). The empirical data are in purely quantitative form and concern exact sizes of indicators. The third phase concerns the design of the Regional Development model, capturing all the stakeholders.

According to the literature review, Soft Systems Thinking (SST) techniques are better to other approaches in coping with complexity and also constitute a response to the rising complexity of innovative systems [9]. In complicated circumstances, SST-based methods are more promising because they allow managers to define the problem in its complete systemic context [10]. Furthermore, understanding the systemic mechanisms that underpin organizational dynamics, according to Maani and Maharaj [11], is a necessary precursor for the creation of robust strategies.

The systematic approach to the innovation process was initially followed by models at the national level Godinho and more recently at the regional and even sectoral level [12], for example the initiative of Living Labs. Literature review reveals that innovation processes are integrated into regional conditions shaping regional innovation systems, which justifies the SST methodological approach as an appropriate method for modelling the decision-making process and understanding the interactions of different stages and between different actors. One method of codifying soft systems is System Dynamics (SD). J.W. Forrester is credited with inventing it in the early 1960s [13]. Organizations are studied and understood most successfully in terms of their shared underlying flows, rather than in terms of distinct functions, using this method [14]. System dynamics makes use of control theory insights, simulation and optimisation to deal with managed systems. According to Coyle [15], the structure of the system dynamics analysis follows a five-stage approach. The first three stages constitute the qualitative system analysis, and the last two stages the quantitative one. The first stage is to recognize the problem. At the second stage comes the description of the system by means of an influence diagram is performed, referred also as a causal loop diagram in System Dynamics. In stage 3 the analyst draws on the so-called bright ideas, by analysing the feedback loops of the system. Work proceeds to stage 4, the construction of the simulation model, concluding with stage 5 where results based on quantitative analysis start to emerge.

In this paper we analyse the first three stages, according to which we result to the policy planning for regional development. Literature review reveals other studies using the SD approach and discussing the qualitative system analysis, with its final step the causal loop diagram formation [16,17]. Any study and comprehension of the overall implications of activities among the associated stakeholders is based on the dynamic behavior of this loop [18].

Next steps of our research constitute the second step of the third phase, which includes the development of mathematical equations, a presentation of the flowchart depicting the structure of the model, and the interactions between the new variables. The fourth phase will follow, where the model will be able to contribute as a "tool" to conduct extensive alternative what-if analysis scenarios, with the aim of exploring the impact of the use of new technologies on the performance of a Regional Innovation System and Regional Development.

III. THE REGIONAL DEVELOPMENT MODELLING

In the present study we present a dynamic model that allows the empirical evaluation of the operation of a regional innovation system. The mathematical model developed in the present study is based on the basic principles presented in the scientific work of Geels [19], which was enriched by the scientific work of Komninos [20] by introducing into the regional innovation system the various bodies operating through digital networks. communication, virtual clusters and internet services. This research is one of the first to approach the RIS with the help of a mathematical model and which studies the interactions that develop between its elements.

RISs usually consist of a set of interacting private, semi-private and public organizations, which interact within an institutional framework. This framework supports the creation, exploitation and dissemination of knowledge and thus supports the creation of innovative activities at the regional level [21-23]. In the literature there are many attempts that try to capture the research that is carried out in a RIS. According to Komninos [24] the structure of RISs can be described by:

- Components, such as innovation companies, suppliers, customers, universities, research organizations, technology transfer organizations, IPR lawyers, consultants, educational institutions, incubators, financial institutions, government agencies, monitoring agencies.
- Knowledge networks. Knowledge is divided into explicit and implicit. "Explicit knowledge" is communicated in official languages, codified and stored in libraries, archives, and databases, but "tacit" information has a personal dimension that makes it impossible to formalize and convey through other forms of personal communication. Morgan explained that tacit knowledge is "spatially sticky", and this property maintains the tendency of innovative activities towards accumulation.
- The institutions Knowledge production, distribution, intellectual property management, knowledge assessment, and financing institutions function as toggle switches, turning funding on and off and making positive or negative judgments regarding the innovation process.
- The result of innovation. The architecture of knowledge networks varies based on the system's innovation processes. Cooperative R&D, strategic intelligence, product innovation, process innovation, spin-offs, new market entry, and the attraction of knowledge-intensive companies are all examples of innovation paths that include fundamentally varied knowledge networks. Different types of innovation require different partners and alliances.

Today, there are new terms involved with global, national and regional development. These are innovation-driven growth, knowledge-based growth and smart growth. These are terms that describe “the rising demand for direct access to all of this by the private and governmental sectors in advanced economies as they become more reliant on knowledge, information, and high levels of skills. Because information and technology have gotten increasingly complicated, connections between corporations and other organizations have become increasingly important as a means of gaining specialized expertise” [25]. Today, the primary role of knowledge and technology in the development and achievement of a competitive advantage is significantly recognized.

At the local and regional level, the path to a knowledge-intensive economy is transforming business clusters into knowledge creation and learning hubs, culminating in global knowledge hubs. Smart growth, on the other hand, is a crucial component of the EU 2020 plan for preserving jobs, research, education, broadband, and ecologically sustainable and inclusive growth. The confluence of innovation and digital strategies, known as "Research and Innovation Strategies for Smart Specialization (RIS3)" and "Digital Development Strategies (DGSs), is required for smart growth. In this view, specialization, business intelligence and discovery, evidence-based development, bottom-up governance, and widespread use of smart technologies and collaborative business models are the drivers of a new growth model.

There is therefore a growing interest in studying the link between innovation, regional development and digital systems and strategies. The model we are developing aims to study the impact of digital technologies and strategies on regional development, as smart environments fill gaps in the innovation supply chain, providing virtual connectivity and resources where local resources and skills are lacking. In addition, according to Sharma et al. [26], this innovation backed by digital environments is leading to a major wave of growth at all levels studied since the 1990s, backed by digital networks, software and new media. The convergence of innovation and digital systems fuels a growth model, the so-called "smart growth model", which is becoming the dominant growth model worldwide.

Innovation systems today have evolved into cyber-physical systems due to the proliferation and widespread use of digital technologies and the creation of digital media in decision making. The figure below illustrates the cyber-natural innovation system (CNIS), whose key components come from the concept of "socio-technical regimes" developed by Geels [19], which refers to the semi-coherent set of rules applied from different social groups involved in the innovation process (users, policy makers, social groups, suppliers, scientists, innovation intermediaries, financial institutions, companies and others). All these components that make up the innovation system are enriched by various bodies that operate through digital communication networks, virtual clusters and online services.

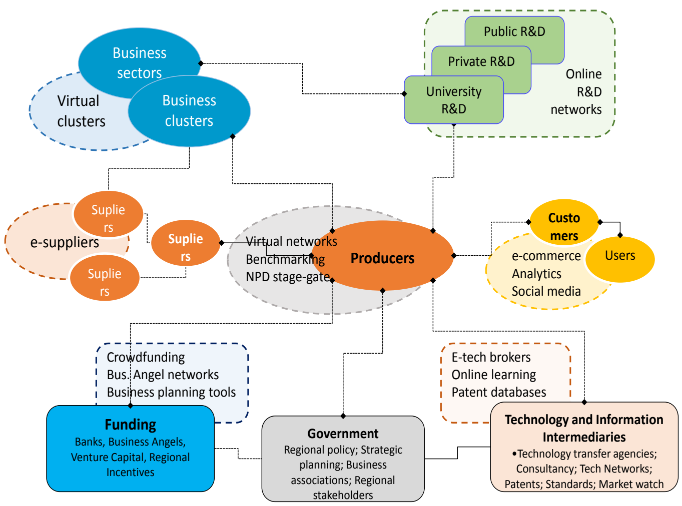

Fig.1. The Regional Innovation System supported by digital technologies and networks (Source: Komninos, 2016)

Based on all the above, we conclude that in order to study the concept of RIS, we need to separate it into the different parts-subsystems of which it consists of. This is because there are different activities that take place within a RIS and all of these activities are carried out by different factors.

To emphasize that RISs do not follow the logic of simple input-output relationships in the process of developing innovations or in developing technological progress for a country. This thinking is central to the systemic approach to innovation [27]. Thus, instead of creating a model that will focus on factors, we create a model that focuses on the operational structure of the RIS in order to delve into the determinants of innovative activities. In this way, our goal is to reject the linear model of innovative processes and to focus on the systemic nature of innovative activity, which is the core of the RIS approach. For the study of the systemic nature, the researchers chose the approach with modeling using the dynamics of systems. Taking into account the above description of the system, below we describe the functional structure of the RIS, with its determining factors. The qualities and behaviors of each factor affect everyone else accordingly. In the present research, the regional innovation system is analysed in six subsystems, namely:

1. ICT capacity subsystem
2. Innovation result and regional development subsystem
3. Institutional framework subsystem (governance and regulatory framework)
4. Knowledge application and exploitation subsystem (businesses, clusters)
5. Knowledge network subsystem
6. Subsystem of production and dissemination of knowledge (universities and research centers)

These subsystems are intended to describe the central points of a RIS and create a complex network of interactions (Fig. 2).

The process by which innovations are developed and integrated into market products is quite complex and can take many forms. The present study examines two of these forms, product innovation and process innovation, which also describe the second subsystem, namely Innovation result and regional development subsystem mentioned above. Knowledge flow of in this subsystem is achieved by creating the capacity for R&D, which is divided into product innovation and process innovation. R&D capability comes from the subsystem of human capital and knowledge capital, which consists of all researchers. The percentage of researchers who will contribute to the development of innovation is determined by the market conditions, the ICT capacity and the institutional conditions in force. It is also worth noting that product innovation precedes process innovation, as after the development of the first from the iterative process results the development of the second.

Product innovation (Prod.In.) increases according to the number of researchers, the percentage of those who contribute to R&D, but also the share of those involved in Prod.In. Process innovation (Proc.In.) on the other hand is changed by the Proc.In growth rate, which is affected by the Proc.In growth rate according to a delay function but also the number of researchers dealing with Proc.In (in a similar way to Prod.In.). Both Prod.In. as well as Proc.In. are reduced according to a rate of depreciation (depreciation of Prod.In. and depreciation of Proc.In. respectively), which is due to the depreciation caused to knowledge over the years. Fig. 2 shows the influence diagram of the calculation of Prod.In. and Proc.In.

Beyond Prod.In. and Proc.In. there is the knowledge network subsystem, which comprises from explicit and tacit knowledge (TK). Explicit knowledge is the result of the research process that comes from R&D capacity. Tacit knowledge on the other hand is a product of the daily operation of businesses and the utilization of both Prod.In. and Proc.In. Both explicit and tacit knowledge are reduced by a rate of depreciation in a manner similar to Prod.In. and Proc.In.

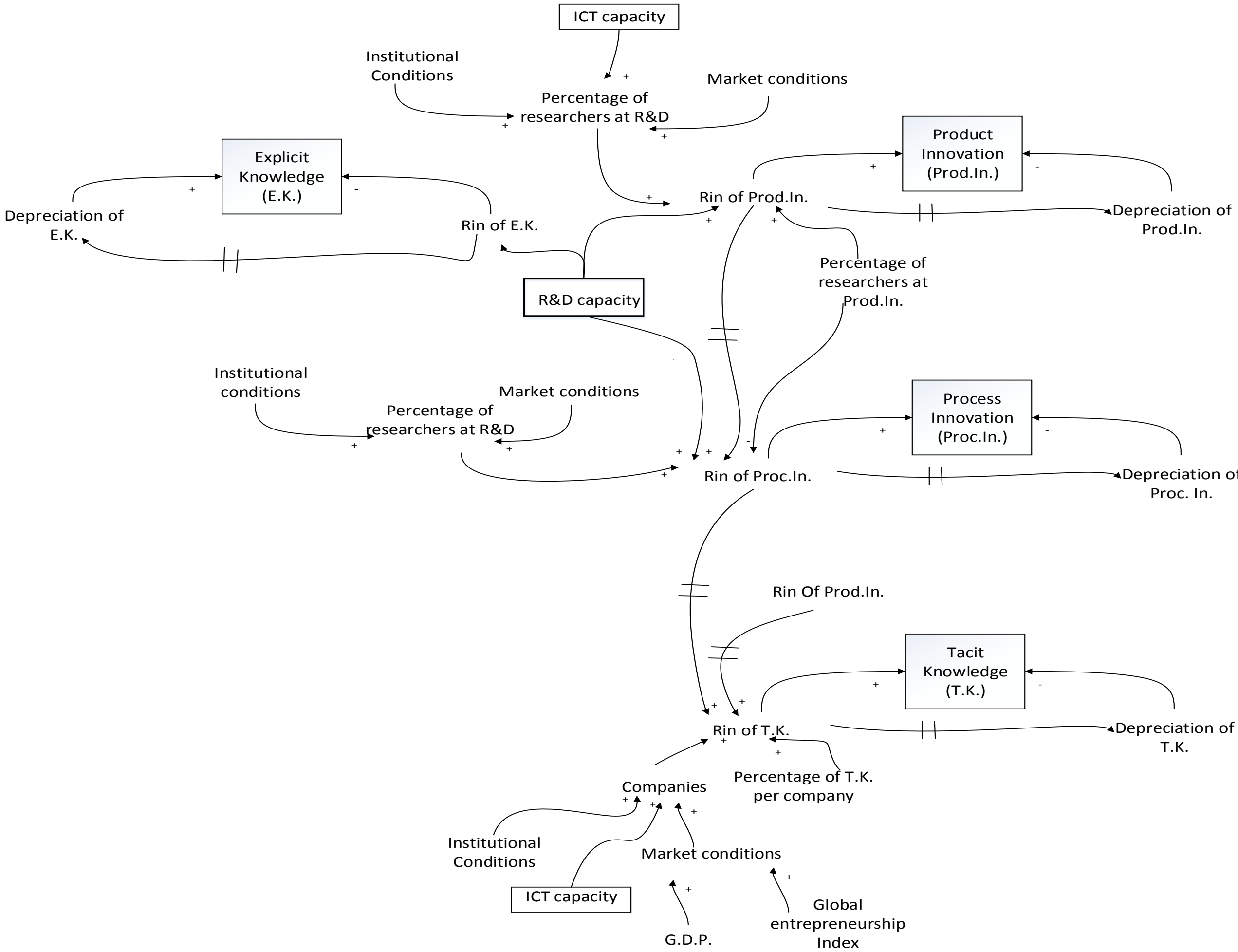

Fig.2. Summary influence diagram

The institutional conditions (Institutional framework subsystem) in turn is changed by the Rate of Change of Institutional Environment, and the depreciation of the Institutional Environment. The Rate of Change of Institutional Environment is changed by the Formation of Institutional Environment which in turn is increased by two variables, the Tax Policy and the Regulatory Framework. The Tax Policy based on the literature is quantified with the help of three indicators, the Tax Impact, Index B and the Tax Level. Respectively, the Regulatory Framework is quantified with the help of two indicators, the Number of Procedures and the Obstacles to Governmental Regulations.

ICT capacity is affected by the following ICT metrics:

- Percentage of the ICT sector on GDP
- Employed person with ICT education
- Employed ICT specialists in total
- Share of enterprises that make B2C e-commerce sales via a website
- Households with a broadband connection
- Number of persons employed in the ICT sector as % of the total employment
- Standard fixed broadband coverage / availability
- Cloud computing services
- Enterprises who have ERP software package to share information between different functional areas
- Enterprises with a website
- Use of social media (% of enterprises)
- Individuals who accessed the internet away from home or work

Prod.In. and T.K. contribute to increasing the attractiveness of products vis-a-vis competitors in order to increase the market share occupied by each company. On the other hand, Proc.In. helps reduce the cost of producing products. The result of all the above is to increase the profit that results per business.

The number of companies fluctuates according to market conditions, Institutional Conditions and the ICT capacity. Market conditions in turn are influenced by the Market Maturity Rate, which in turn is increased by the Market Maturity Format, the Global Entrepreneurship Index and the GDP. he Formulation of Market Conditions is increased by the Formulation of Market Size & Wealth, the Formulation of Market Opening and by the Formulation of Macroeconomic Conditions. Market Opening Configuration is increased by two variables, the Scientific Activities and the Technological Trade. Scientific Activities are enhanced by two indicators of the literature, Talent Leakage and Scientific Collaborations. Technology Trade is comprised by four indicators, IDI/GDP (international direct investment per gross domestic product), Imports / GDP, Exports / GDP and Exports of High Technology Products as a share of total exports. Finally, the Formation of Macroeconomic Conditions increases by three indicators, Inflation, Public Deficits and Public Debt.

The total budget for R&D is increased by the State R&D Grants, the amount from the university budget for R&D and the Private Enterprise R&D Grants. On the other hand, the total R&D budget is reduced by the total costs incurred for R&D, and more specifically both researchers' salaries and other operating costs for successful research and development. Private Enterprise Grants in turn are affected by both the total number of enterprises and the amount of subsidy each business returns, a variable that increases as the innovation culture grows. In order to increase the culture of innovation, appropriate innovation promotion programs are created, which are also part of the total R&D budget expenditure. The amount of Government grants is determined by the GERD price corresponding to each region, and by its population. The population of the region is affected by the Gini value (regional inequality calculation index) corresponding to that region, with an inversely proportional correlation.

IV. DISCUSSION AND CONCLUSIONS

An extensive literature review of empirical research on the impact of digitization on innovation systems found that there were not many contributions to the literature that went beyond simple descriptive analysis. This was one of the main reasons why the researchers of the present study showed interest in this field of research. Therefore, firstly, the present research covers the gaps identified in the literature regarding the study of the effect of digitization on innovation systems using simulation.

The use of system dynamics theory is another scientific originality, as the studies so far were based on descriptive analysis, giving only simple comparative results between the different systems. The systems dynamics approach enables the development of regional development improvement scenarios with the help of simulation. So, a dynamic model is being developed, specifically designed to study the impact of digitization on regional development at the regional level. The research contains extensive numerical results on the regional development of two Greek regions, from the different digitization policy scenarios being studied.

This study is implemented using abductive reasoning in order to make logical inferences and construct the framework's theory based on the work proposed by Komninos [20], where the need of support of digital technologies and networks to the function of a Regional Innovation System is presented. To accomplish so, this framework's system dynamics were employed in conjunction with a modeling method. System dynamics is a branch of science concerned with the development of models that accurately represent the operation of real systems, allowing them to be studied dynamically. The need for this approach derived by the fact that RISs consist of multiple variables, each of which is associated with its own pace and direction of change, which are causally related to the production of patterns of change in each system [28]. In this article the causal-loop diagram of the regional innovation system is designed. The model comprised of six subsystems. These subsystems are intended to describe the central points of a RIS and create a complex network of interactions as it has been described above. The ICT capacity influences the innovation result and regional development subsystem, the institutional framework subsystem (governance and regulatory framework), the knowledge application and exploitation subsystem (businesses, clusters) as well as the subsystem of production and dissemination of knowledge (universities and research centers) of the RIS and affects its operation, leading the system in the design and implementation of innovation-based strategies.

Next steps of our research constitute the development of mathematical equations, a presentation of the flowchart depicting the structure of the model, and the interactions between the variables. Finally, multiple alternative what-if analysis scenarios will take place, with the aim of exploring the impact of new technologies on regional development.

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