LUND UNIVERSITY

School of Economics and Management

Master Programme in Economic Growth, Innovation and Spatial Dynamics

# On the Way to Developing the Triple Helix Indicator

## Contribution from Quantitative Empirical Studies

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***Abstract:*** In this paper, review and appraisal of twelve quantitative empirical studies in the stream of the Triple Helix model is performed in order to synthetize current knowledge on development of the quantitative Triple Helix indicator as well as to suggest some hypotheses and recommendations for the further research. Studies under consideration represent six approaches towards measuring Triple Helix relations, namely: mutual (configurational) information among three helices, φ-coefficients and partial correlation; embeddedness indicators; graphical representation of Triple Helix relations using the Vector Space model; patent-based indicators; and, regression models. Different approaches are analyzed in terms of their theoretical and methodological foundations, used data, dependent/independent variables, considered Triple Helix relations (bilateral, trilateral, etc.) as well as their perspective on the Triple Helix model (neo-institutional/neo-evolutionary). The results of the study have shown that (1) instead of developing single Triple Helix indicator, it is necessary to establish a system of indicators; (2) there is a need to perform empirical research on bilateral university-government and industry-government relations from the perspective of the Triple Helix model; and, (3) operationalization of bilateral relations in terms of quantitative variables requires developing multidimensional vector variables.

***Keywords:*** knowledge-based economy; Triple Helix; university-industry-government relations; indicators; measurement.

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# I. INTRODUCTION

Transformation to the knowledge-based economy, which started in the last decades of the twentieth century, raised the questions of importance of innovation and knowledge for development of economic systems. How do innovations emerge and develop? How is knowledge created and distributed? What are the determinants of successful innovation activity? How can innovations help to promote successful economic performance? Social, economic, and political research, driven by these questions, resulted in development of some theoretical models and concepts, which became highly influential in recent years, namely: clusters (Porter 1998), national systems of innovation (Lundvall 1988, Nelson 1993), regional innovation systems (Cooke 1992), "Mode 2" knowledge production (Gibbons et al. 1994), and Triple Helix model (Etzkowitz & Leydesdorff 1995, 2000). All of them, though from different perspectives and with different theoretical background, justify the important role of innovation and knowledge infrastructure for the development of economic systems at different levels (e.g. regional, national, supra-national, etc.).

Today, these models are often considered by authorities when designing innovation and technology policies. For example, Swedish Governmental Agency for Innovation Systems (VINNOVA) employs systems of innovation and Triple Helix concepts as the theoretical framework for programs and policies fostering public-private relationships (Jacob 2006). This implies one issue: in order to evaluate effectiveness of a policy, authorities may need quantitative indicator(s), which would directly reflect results of the policy implementation. However, none of the above-stated models and concepts entertains such an indicator, which has proven its reliability in analyzing current situation in an economic system and predicting results of the policy implementation and/or influence of shocks, which are external to the system.

Therefore, development of the indicators for analyzing innovation activities of the economic system under the theoretical framework of the above-stated models should become one of priority research directions for the economists and social scientists. This paper is one of the attempts in this field.

I decided to concentrate my attention on the Triple Helix model, which was firstly introduced by Henry Etzkowitz and Loet Leydesdorff in 1995. The original idea of the model was that in a process of transformation to the knowledge-based economy previous knowledge production infrastructure, represented with separate institutional actors of university, industry and government, is being replaced with a growing overlay of reflexive communications between them (Etzkowitz, Leydesdorff 2000). Given that, an enhanced role of universities in innovation is underlined.

Though, to date quite a large number of quantitative empirical studies in the stream of the Triple Helix model have been carried out by different authors, there were no attempts to systematically review and analyze their theoretical, methodological, etc. features. However, such type of study would be useful for further research aimed at developing the quantitative indicator for the Triple Helix model.

The aim of this paper is, therefore, to perform the review and appraisal of the quantitative empirical studies, performed in the stream of the Triple Helix Model. Achieving this aim will require solving the following tasks:

- comparing the methodology used for constructing the indicator in each of the studies;
- reviewing the indicators in terms of their reliability and relatedness.

In general, in this paper I will try to synthetize current knowledge on development of the quantitative Triple Helix indicator as well as to suggest some hypotheses and recommendations for the further research. Besides, I hope that this paper will help the future researchers, wishing to perform quantitative analysis in the stream of the Triple Helix model, to design their research taking into the consideration shortcomings and strengths of previous studies in terms of methodology, data, theoretical background, etc.

In the following, I will introduce research focus, theoretical framework, and main features of the Triple Helix model, review main critical points towards it and discuss possible future developments of the model (*Section II*)[1]. After that I am going to introduce methodological issues of my research (*Section III*). In *Section IV* I will perform detailed analysis of single studies in order to determine the specific features characterizing each of them[2]. *Section V* is aimed at synthesizing the results of the analysis performed in Section IV, discussing possible hypotheses and recommendations for the further research as well as limitations of this study, and providing the reader with some final remarks.

[1] I do not have the intention to defend the model against the critics (with the only exception if the development of the model in response to critics has been made).

[2] The emphasis will be mostly made not on the results of singe studies, but on the way the results were obtained, i.e. the research design.

## II. GENERAL INSIGHT INTO THE TRIPLE HELIX MODEL

The Triple Helix metaphor is not a new idea in the history of science. For example, it was suggested as a form of the DNA molecule by Pauling and Corey in 1953[3] and as an approximation for the relations between genes, organisms and environments by Lewontin in 2000 (Leydesdorff 2006). In a similar manner as Lewontin, though in the different context, Etzkowitz and Leydesdorff developed the Triple Helix model for studying the relations between university, industry and government[4] in the knowledge-based economy (Etzkowitz and Leydesdorff 1995).

The model came as the result of bringing two streams of research together, namely: analyzing knowledge infrastructure from the institutional perspective (Etzkowitz 1990) and performing the evolutionary analysis of economic growth based on development of the knowledge base in an economic system (Nelson 1994). Hessels and van Lente (2008) claim that the Triple Helix model lacks a uniform research message, but rather formulates the research program. Therefore, while being considered as an evolutionary model of development and diffusion of new knowledge and innovation, research in the stream of the Triple Helix model from the very beginning was performed in two perspectives: <u>*neo-institutional*</u> (currently supported by Etzkowitz) and <u>*neo-evolutionary*</u> (currently supported by Leydesdorff)[5]. In order to understand the theoretical context and implications of the Triple Helix model, it is necessary, first of all, to introduce both perspectives in detail.

### *II.1. Neo-Institutional Perspective on the Triple Helix Model*

Neo-institutional perspective on the Triple Helix model acts as an operationalization of an innovation system (regional, national, etc.) through specifying its main institutional actors: university, industry and government. The main focus of analysis in this case is made on the networked interrelationships between these spheres.

In terms of the theoretical background, this perspective bases on the ideas from evolutionary economics as well from classical social theories: Simmel's analysis of triadic relationships, Marx's theory of differentiated social spheres, and Weber's theories of social organization and hierarchies (Etzkowitz 2008).

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[3] Though it was later rejected in favor of the double helix structure, suggested by Watson and Crick in 1953 as well.

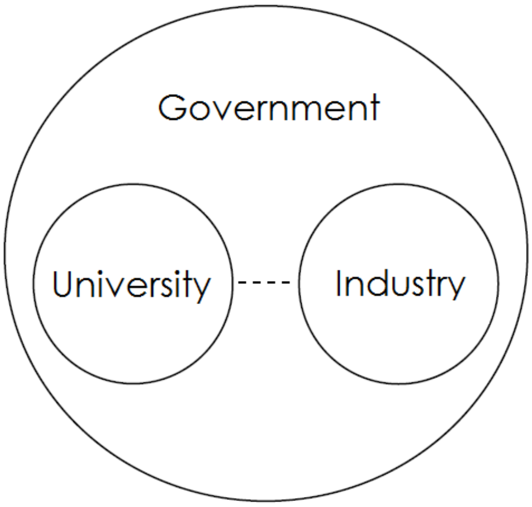
[4] Here and further, university, industry and government are treated as aggregated actors comprising all universities, industries (business, companies) and public authorities in country, region, etc.

[5] Leydesdorff (2011) mentions that because of tensions between the approaches to the model he and Etzkowitz decided to stop co-publications in mid-2000s

Neo-institutional perspective suggests that development of an economic system in the situation of increasing importance of knowledge and innovation is enhanced, when during internal transformation main institutional actors (university, industry, and government) start "taking the role of each other" (Etzkowitz 2008, p. 9), while stimulating interrelations among them and forming, therefore, interactive trilateral relationships. This overlay of communications becomes as important for the dynamics of the system as the original knowledge infrastructure of university, industry, government and bilateral relations among them.

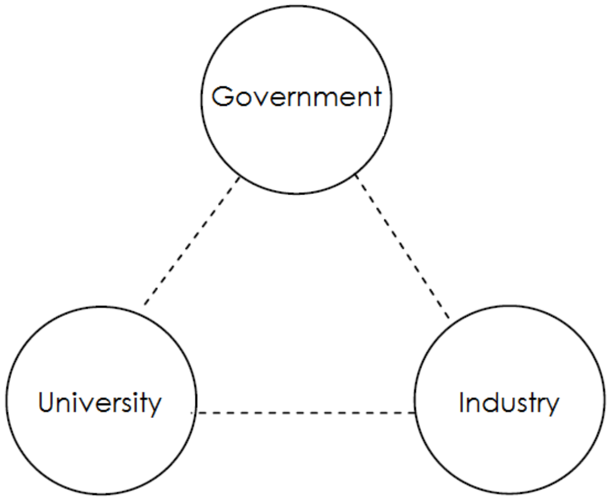
However, such structure of institutional arrangements in the system is not given naturally – it is developed from one of the opposing standpoints: etatistic (statist) society (Figure 1) or "laissez faire" society (Figure 2)[6].

***Figure 1. Etatistic (Statist) Society***




*Source: Etzkowitz, Leydesdorff 2000, p. 111*

***Figure 2. "Laissez Faire" Society***




*Source: Etzkowitz, Leydesdorff 2000, p. 111*

In statist societies government acts as a dominant institutional actor, which coordinates the relations between university and industry, and plays the main role in developing new initiatives[7]. Such societies may be found, for example, in developing countries of Latin America and Eastern Europe.

Sábato (1968), studying the case of Latin American countries, suggested the so-called "Triangle" technological model, which is still used as the framework for analyzing the innovation systems in the developing countries (see, for example, Arocena and Sutz 2005). In his model, Sábato employs the statist society model for analyzing the knowledge infrastructure

[6] In these cases, one can also talk about 'weak' Triple Helix configurations.

[7] Etzkowitz (2008) develops the term of *Innovation Organizer* as "an organization that takes the lead in enunciating a development goal and coordinating cooperation among a group of organizations to carry it out" (Etzkowitz 2008, p. 82). This definition may be applied to institutions on different levels of an economic system: regional, national, etc.

of developing countries. Sábato distinguishes three types of institutional spheres: scientific and technological infrastructure, productive infrastructure and government (Arocena, Sutz 2005, pp. 8-9)[8]. He claims that in developing countries only government has the resources and capabilities for coordination of development of the knowledge base of the economy (Arocena, Sutz 2005). Etzkowitz (2008) suggests that such institutional arrangement may be effective only on the initial phase of development of national innovation system. However, the need for boosting the effectiveness of the system impels the changes in the society through introduction of new sources of initiative. The statist society is then transformed into "laissez faire" or Triple Helix (see below) society.

When it comes to the "laissez faire" society, it is not government, but industry that acts a prime mover of economic system development. The role of the government in this case is limited to solving the problems of the so called "market failures", which is supported by liberal political agenda and neo-classical economic school.

In such society, the institutional spheres of university, industry and government are clearly divided, and the relations between them are performed *ad hoc* on the bilateral basis across decently defended boundaries (Etzkowitz 2008, p. 16). Each of the spheres is supposed to be appointed to the functions on the one-to-one basis: university for the basic research, government for the normative regulation and industry as a productive force.

With the development of the knowledge-based economy there can be distinguished two major transformations, which shape the brand-new structure of innovation system: firstly, formation of reciprocal relations between institutions in the system on the constant basis, and, secondly, replacement of industry by university as a core institutional actor (Etzkowitz 2008).

Metcalfe (2010) distinguishes 3 steps of this transformation, which reflect the evolutionary aspect of the model:

1. *internal transformation in each of the institutional actors, during which they "take the role of each other"* – for example, while keeping the core competencies for education and basic research, universities may take the "third mission" of wealth creation through firm formation, business oriented research, etc.[9];
2. *formation of the new overlay of trilateral relations among the institutional spheres* –

[8] These three spheres are definitionally very close to the university, industry and government in the Triple Helix model.

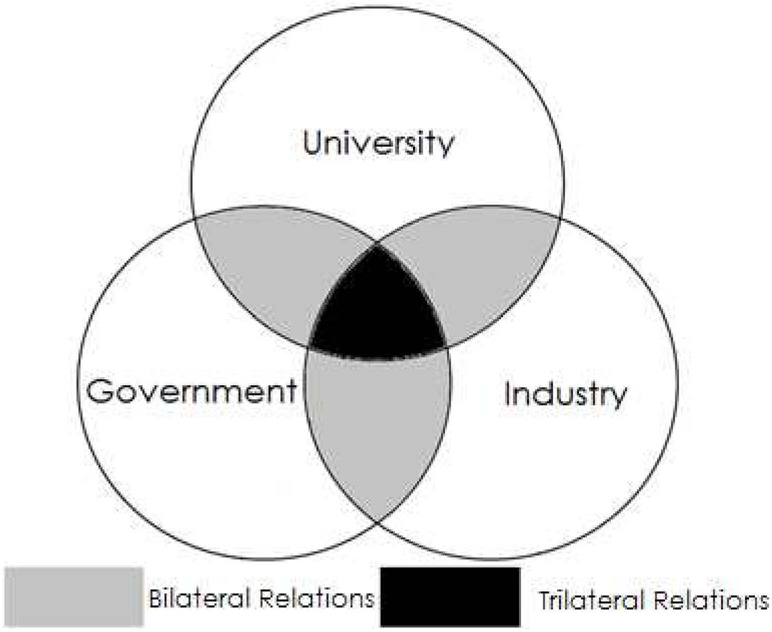
[9] However, such "third mission" is not supposed to replace the core mission of education and basic research.

one example of such an overlay is creating a science park, in which private companies acquire technologies and knowledge, developed in a university, with the financial support of governmental agencies (science park, in this case, acts as an intermediary organization between three actors);

3. *recursive development of the Triple Helix networks*[10] – development of the Triple Helix relations depends both on developments in each of the helices (or institutional actors) and on the past configuration of the networked overlay of relations.

As a result, the complex system of relations is developed, forming, therefore, some kind of a hierarchy of internal dynamics of each of the components, bilateral and trilateral relations among them (Figure 3)[11].

***Figure 3. Triple Helix Society***




*Source: Etzkowitz 2008, p. 16*

In this system, traditional university transforms into the so-called "entrepreneurial university", which becomes the main institutional actor in the system. Such form of a university is based on 5 norms (Etzkowitz 2008):

- *capitalization of knowledge* – knowledge production and transfer should be driven by means of practical application and product development as well as disciplinary advance[12]. This type of knowledge production is, as well, the main idea in the

[10] In the other words, path dependent development along a trajectory.

[11] According to Weber, complex systems always imply some kind of hierarchy (Leydesdorff 2011).

[12] In the other words, produced knowledge should have theoretical, methodological, and commercial perspectives.

"Mode 2" thesis (Gibbons et al. 1994);

- *interdependence* – close reciprocal relations with industry and governmental agencies;
- however, entrepreneurial university should keep its *independence* from the other institutional actors;
- *hybrid organization* – combination of "core" and "supportive" missions of knowledge production and contribution to the society;
- *reflexivity* – continuing reflexive reconstruction of the internal structure of a university as well as its networks.

While some universities were found as the entrepreneurial ones (e.g. Linköping University in Sweden, established in 1969), most of universities are more or less passing the transformation period, during which they are bringing their internal characteristics in alignment with the above-stated norms. However, as Viale and Pozzali (2010) argue, such transformation takes place mostly in competitive university systems, like in the US and Great Britain, where most universities are private and competing for students and funding (both private and public). At the same time, state owned universities in continental Europe are not following this path (or are transforming very slowly), not to mention universities in developing countries. This brings up the question of relevance and generalizability of entrepreneurial university concept.

To sum up, the neo-institutional perspective on the Triple Helix model comes as one of the approximations for the structure of an innovation system (national, regional, etc.). The evolutionary character of the model is reflected in the mechanism of transformation to the Triple Helix society. The bigger role of an entrepreneurial university is strongly underlined.

### *II.2. Neo-Evolutionary Perspective on the Triple Helix Model*

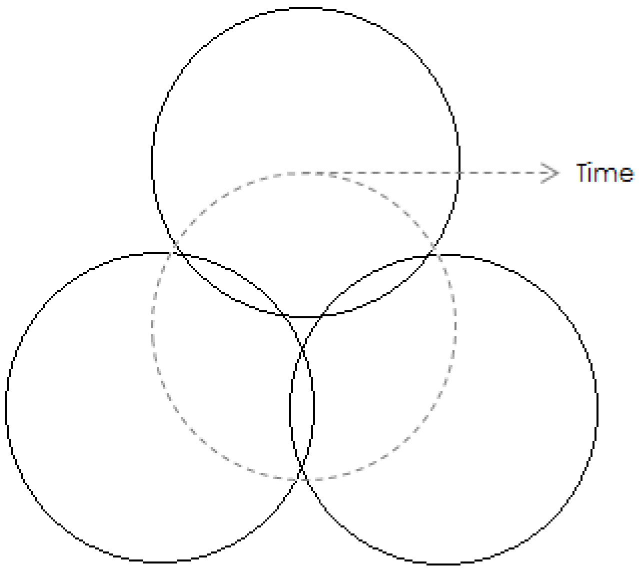
Neo-evolutionary perspective on the Triple Helix model looks at the same issues from different angle. Leydesdorff (2001) claims that it becomes more difficult to match the institutional actors (university, industry, and government) with their functions on the one-to-one basis, when it comes to the aggregate level (region, nation, etc.)[13]. Therefore, instead of distinguishing between Triple Helix of institutions, Leydesdorff and Meyer (2006) suggest to concentrate on Triple Helix of functions: wealth generation (or, knowledge exploitation), knowledge (novelty) production and normative control. Neo-evolutionary perspective is aimed at studying possible synergies between these functions, which are supposed to enhance

[13] This happens, among the other reasons, because of forming mutual relations and "taking the role of each other" (see Section II.1.).

development of the knowledge base in the national (or, regional) innovation system.

The graphical representation of neo-evolutionary Triple Helix is different from – if not opposing – neo-institutional one (Figure 4).

***Figure 4. Hypercycle in the Neo-Evolutionary Triple Helix Model***




*Source: Leydesdorff 2011, p. 7*

As follows from Figure 4, opposite to neo-institutional Triple Helix there is no overlap between the three helices (Leydesdorff (2001, 2008, 2011) talks about the 'negative overlap'). However, all functions are highly interdependent: when two of the helices form bilateral relations, the third helix acts as a selection environment (context) through having mutual relations with each of the first two (but not with their interaction). Therefore, that third element reduces the uncertainty in the system, when two helices interact. Brought together, on the level of a system such selective environments form the synergetic mechanism, which enforces the systemness of an economic as well as innovation system and its ability for self-organization (Leydesdorff 2011). This synergetic mechanism acts as the next-order system (the hypercycle in the Figure 4), coordinating the helices over time.

The synergies between two of the helices evolve, since as Poincare (1905) has shown that double helices can stabilize in a co-evolution (Leydesdorff 2003, p. 447). These synergies are very important for the development of a national system of innovation. The co-evolution between knowledge exploitation and knowledge production under some circumstances may form the technological trajectory, because of interdependence between demand for and supply of technologies. The synergy between knowledge production and normative control may give impetus for formation of a national innovation system or enforce changes in it. The relations between knowledge exploitation (wealth generation) and normative control define the general structure of an economic system.

The dynamic character of the neo-evolutionary perspective is reflected in the analysis of three subdynamics, underlying general dynamics of an economic system, in the whole, and an innovation system, in particular. In the industrial economy only two subdynamics are prevalent: (1) markets' dynamics seeking for equilibrium; and, (2) state control mechanisms along the public-private interface (Leydesdorff and Zawdie 2010). However, the transition to the knowledge-based economy means that the third dynamic mechanism is added into the consideration, namely dynamics of socially organized knowledge production, which is disturbing markets' equilibrium. Movement both towards markets' equilibrium and against it means that the whole system cannot be expected to be stable, which supports the idea that triadic relations may contain all the sorts of chaotic behavior (Etzkowitz and Leydesdorff 2000).

To sum up, neo-evolutionary perspective on the Triple Helix model is different from neo-institutional one in its vision of the individual helices (Table 1).

Instead of institutions, neo-evolutionary perspective puts functions forward. Dynamics of knowledge production becomes the crucial element of the knowledge-based economy. In general, neo-evolutionary perspective treats Triple Helix as the dynamical mechanism, underlying a national innovation system and leading its transformation.

***Table 1. Neo-Institutional versus Neo-Evolutionary Appreciation of the Triple Helix Model***

| Neo-Evolutionary perspective | Three Subdynamics | | |
|---|---|---|---|
| Functions | Wealth Generation | Novelty Production | Normative control |
| Carriers in the Neo-Institutional Perspective | Industry | University | Government |

*Source: Leydesdorff and Meyer 2006*

### *II.3. Theoretical Context of the Triple Helix Model*

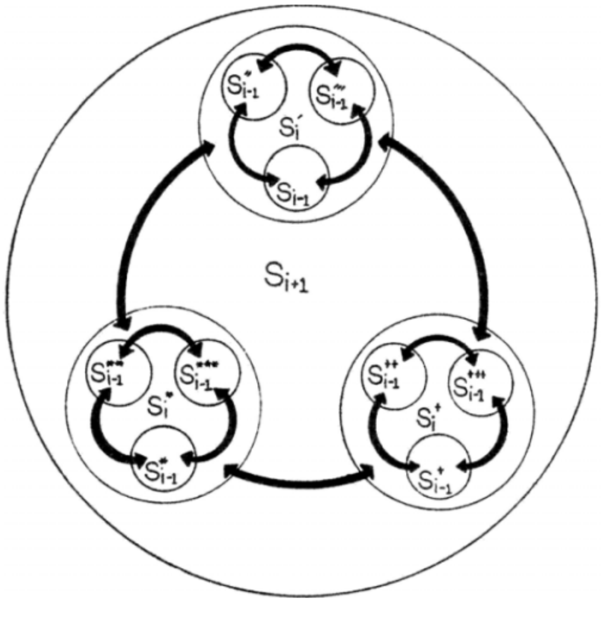
As it was already stated above, the Triple Helix model is far from being parallel to the national (or, regional) innovation system concept, but is rather complementing it with structural formalization (in the neo-institutional perspective) or with underlying dynamic mechanism (in the neo-evolutionary perspective). As Balzat and Hanusch (2004) argued, the Triple Helix model enriches the limited knowledge on stability and structural dynamics of innovation systems.

However, while systemic approach to innovation requires having the boundaries of a system (national, regional, sectoral, etc. systems) (Edquist 2004), Triple Helix relations may go far beyond these borders (Leydesdorff and Zawdie 2010). This is reflected in development of international co-authorship relations (Leydesdorff and Sun 2009) or development of transnational companies (in both sectors of large companies and SMEs). The question, however, is if we should distinguish between triple helix configurations on different levels of an economic system (e.g. national and regional), and, if yes, how we can do that.

As well as system of innovation concept, the Triple Helix model is considered as non-linear model of innovation. Non-linear models of innovation develop a linear approach by taking recursive and interactive institutional interrelations into account, changing, therefore, the relations between input and output (Etzkowitz 2008, Balzat and Hanusch 2004, Etzkowitz and Leydesdorff 2000). This is also important since linear input/output relations of individual actors are the unit of analysis in neoclassical economics, and change in these relations shifted the view of the Triple Helix model to institutions and functions as the carriers of economic and technological change, which is more typical for evolutionary economics (Nelson and Winter 1982).

Evolutionary self-organizing character of the Triple Helix model is also underlined in its dynamic aspect.  Goguen and Varela (1979) suggested a holographic model of three interacting dynamics, in which current configuration of a system depends on previous configurations (Figure 5). Leydesdorff and Etzkowitz (2000) extended this model by adding recursive dynamics of individual institution or function into consideration.

***Figure 5. Holographic Model of Three Interacting Dynamics***




*Source: Goguen and Varela 1979, p. 34*

Adding the recursive dynamics of the Triple Helix to interaction effects of Goguen and Varela model brings an additional uncertainty to a system, leaving it in an "endless transition"

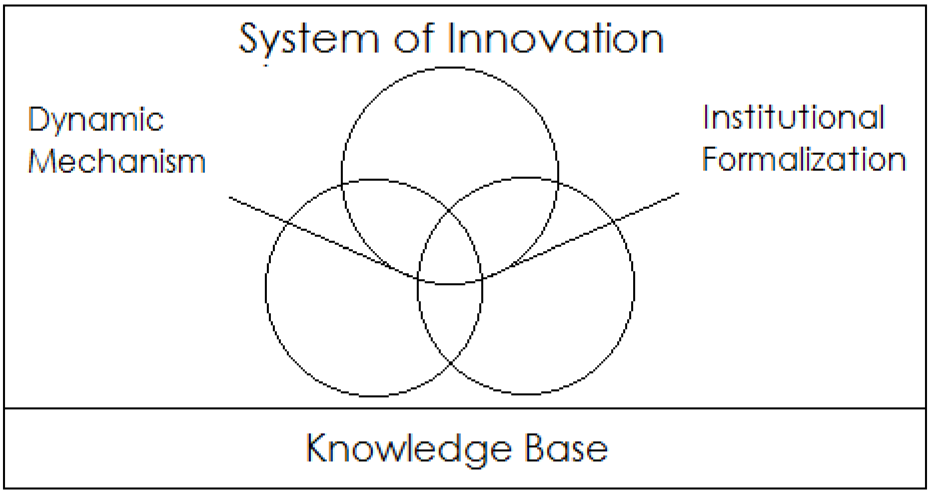
(Etzkowitz 2008).

One more concept, related to the Triple Helix model, is "Mode 2" knowledge production. Its main thesis is that in the knowledge-based economy there is a shift towards interdisciplinary science, which takes place in the context of application (Gibbons et al. 1994). This means that science is driven primarily by social and economic forces of knowledge applicability, rather than by movement to disciplinary advance. Therefore, if we look at development of a university (neo-institutional perspective) or knowledge production dynamics (neo-evolutionary perspective) in the Triple Helix model, we may conclude that these concepts are closely related.

On the other hand, "Mode 2" concept takes into consideration only one aspect of innovation system (knowledge production), while Triple Helix perspective on innovation systems is wider. Besides, while "Mode 2" thesis claims that boundaries between university and surrounding environment are almost totally blurred (Gibbons et al. 1994), universities in the Triple Helix model keep their autonomy, but develop the reciprocal relations with the other institutional spheres.

Concluding the discussion on the theoretical context of the Triple Helix model, it should be mentioned that the Triple Helix may act as institutional formalization and/or dynamic mechanism underlying an innovation system (Figure 6).

***Figure 6. Triple Helix in the Context of Innovation System***




Besides, the model represents a non-linear approach to innovation and knowledge production explaining formation of the knowledge base of an innovation system.

### *II.4. Critique of the Triple Helix Model*

As it comes from above, the Triple Helix model introduces many important changes taking place in a process of transition to the knowledge-based economy. However, several major weaknesses and limitations of the model should be distinguished.

One of the main critical points towards the model is that it has a high level of abstraction (Cooke 2005). Tuunainen (2005) claims that in the Triple Helix model three institutional actors are just introduced without decent analysis of them. It is necessary to say, however, that in the book, "*The Triple Helix: University-Industry-Government Innovation in Action*, published in 2008, Etzkowitz devotes three chapters to the analysis of transformations in each of the helices, bringing, therefore, some clearness to the model.

Closely related is the point that the Triple Helix model failures to recognize the national setting that influences university, industry and government (Shinn 2002). Elzinga (2002) argues that the model seems to be functioning in the "deinstitutionalized, fluid and amorphous environment". This point seems relevant, since there are big differences in innovation systems of different nations (Balzat and Hanusch 2004), which are not considered in the model.

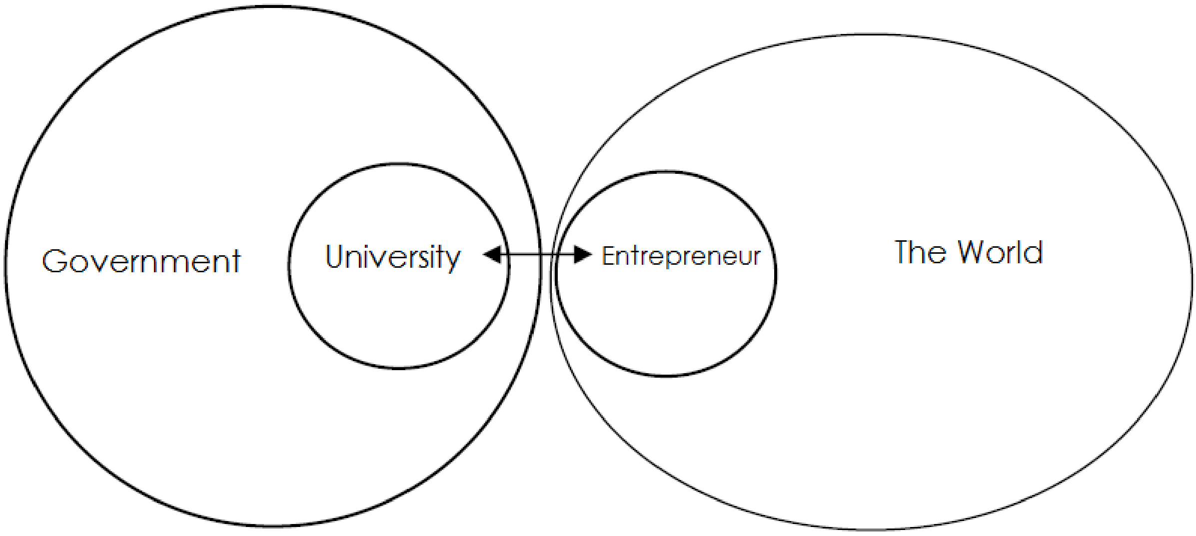
These two points made some researchers conclude that the Triple Helix is not the theoretical concept or model, but rather a normative political agenda for developing countries (Elzinga 2002, Tuunainen 2005, Shinn 2002).

From the other perspective, Viale and Pozzali (2010) criticized the Triple Helix for being a lock-down model, lacking "a solid micro foundation". Brännback et al. (2008) deepened this point, arguing that the Triple Helix model totally ignores people, who are initial drivers of the innovation process[14]. They suggest that innovation system is viewed differently from researchers and entrepreneurs. Researchers consider innovation system as the "laissez faire" society (see Figure 2), where interactions with industry and gvernment happens on *ad hoc* basis and is limited. For the entrepreneurs, on the other hand, universities and government are considered as "parallel universe" (Figure 7). Thus, the Triple Helix model tends to simplify the real situation in the innovation system.

Case study, performed by Tuunainen (2002), has shown that universities are much more resistant to changes than this is suggested by the Triple Helix model. Tuunainen showed that (1) there are difficulties in creating hybrid university-industry structures for transfer and/or commercialization of technologies; (2) issues of property rights may provoke conflicts between researchers and university management; and (3) even in case of successful development of entrepreneurial university, its impact on the society is not that significant as it is claimed by the model. The latter point was also supported by Elzinga (2002).

[14] Brännback et al. (2008) performed interviews with 50 Finnish innovators and entrepreneurs.

*Figure 7. Entrepreneurs' View on the Triple Helix*




*Source: Brännback et al. 2008*

Summarizing, main critical points towards the Triple Helix model can be grouped into four categories:

1. abstract character of the model;
2. failure to recognize the national setting;
3. lack of micro-foundation;
4. weaknesses in explaining university-industry collaboration.

All these points made Elzinga (2002) conclude that Triple Helix model is promoting particularism, while claiming for generality.

### *II. 5. Research Agenda for the Future*

Four above-stated critical points to the Triple Helix model reflect directions, in which further research should be made. Researchers of Triple Helix should concentrate on the issues of micro-aspects of the model, peculiarities of Triple Helix in different national (or, regional) innovation systems as well as bilateral and trilateral relations between individual helices. Such questions may be, for example, addressed in case studies.

Although pretty a lot studies were devoted to university-industry collaboration (e.g. Dosi, Llerena, Sylos Labini 2006; Shinn, Lamy 2006) as well as industry-government relations (e.g. Feldman, Kelley 2006), there is still a limited insight into the nature and development of university-government relations and trilateral relations of university-industry-government (in the neo-institutional perspective on the model) or hypercycle of three subdynamics (in the neo-evolutionary one).

The other possible development of the model is extension to Quadruple Helix, Quintuple Helix, or, in general, to N-tuple of helices. For example, Carayannis and Campbell (2009) suggested that the model should include the forth helix, namely, "media-based and culture-based public", since the general culture and values as well as influence of media mechanisms have an effect on development of innovation culture, which may transform any national system of innovation. The other case, is inclusion of international co-authorship relations as a forth helix to the model (Leydesdorff and Sun 2009), which helped to reveal some interesting features of Japanese national innovation system.

Such an extension may be a relevant point, however, this should be justified, both theoretically and methodologically. Besides, each new helix will require decent specification and operationalization of new components of the model (Leydesdorff 2011). Therefore, while extending the model beyond Triple Helix, one should be very cautious about the consequences.

Finally, as it was already stated in the introductory part of this paper, there is a big challenge for developing the quantitative indicator, based on the Triple Helix model, which would be able to illustrate the current situation in the innovation system, dynamics of its development, results of policy implementation, etc. As I claimed in Introduction, this direction should become one of priorities for the future research.

Further, I will summarize the findings of the Triple Helix quantitative empirical studies, performed to date, which may be helpful for the development of such quantitative indicator.

## III. METHODOLOGY

The research, underlying this paper, was performed in the form of explorative literature review with elements of critical appraisal of methodology, theoretical framework and data used by different authors as well as applicability and generalizability of different studies.

Choosing literature review as the method for the research imposes specific liabilities to find and include as much relevant studies in the field as it is possible. Therefore, it was important to correctly define (1) search criteria (keywords and sources of data); and, (2) inclusion criteria.

In order to find relevant literature, the following search mechanisms were used:

1. *electronic database searching* – search in LibHub and Lovisa databases of Lund University Libraries;
2. *manual searching at the key journals pages in the Internet* – the journals under consideration were *Research Policy* and *Scientometrics*;
3. *searching at the researchers web-pages* – personal web-page of Loet Leydesdorff (one of two founders of the Triple Helix model) – www.leydesdorff.net;
4. *general search engines in the Internet* – Google and Google Scholar search engines;
5. *following the citations in the found papers*.

The keywords for the search included different combinations of the following: "triple helix", "innovation", "regional development", "quantitative analysis", "measurements", "triple helix linkages", "university-industry-government relations", "dynamics", "metrics", "innovation systems", and some others.

The found articles were then screened through and sorted into two groups (a) non-relevant for the study; and (b) relevant for the study. The sorting was performed according to the following options:

1. analyzing Triple Helix relations, discussing regional development in terms of the Triple Helix model (Yes/No);
2. using the quantitative data (Yes/No);
3. using statistical and econometrical methods for determining causal relationships between different variables (Yes/No).

Inclusion criterion (for relevant articles) was formulated in the following way – having "Yes" for all three above-stated options[15].

Following the stated above procedure, twelve quantitative empirical studies were found, and all of them were included in the further analysis.

One important remark should be made here, which indicates one of the main limitations of the research. A half of the included studies (six) were performed by Leydesdorff alone or in collaboration with the other researchers. From that point it is clear that those studies are very close to each other in terms of methodology and data used (though, for different regions). On the other hand, one can mention clear developments in the methodology and operationalization of the variables used from the first study (Leydesdorff, Dolfsma and van der Panne 2004) to the last one (Leydesdorff and Sun 2009). Therefore, the analysis will help to see, how the model transformed during the studied period, which may be helpful for developing recommendations for further research.

The logic of the research required following two subsequent methodological steps, which allowed performing the critical appraisal of different studies.

In the first step, each of the studies included in the research was analyzed separately in order to determine the specific features characterizing it (methodology, data, theoretical background, hypotheses, etc.)[16]. For the more detailed criterion system, see Table 2.

In the second step, on the basis of revealed characteristics of each included study the synthesis of the results was performed, taking into account strengths and weaknesses of different approaches. This synthesis had its goal in developing research questions, hypotheses and recommendations for prospective studies[17].

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[15] One thing should be mentioned here. Of course, it would also be useful to consider qualitative papers, which could provide some recommendations for developing the Triple Helix indicator. However, the number of qualitative empirical studies in the stream of Triple Helix model is at least twice more than quantitative ones. The limitation of time, therefore, made such inclusion not possible.

[16] In this step, the deductive approach was used.

[17] This step suggests having the inductive approach.

***Table 2. Criteria for Analyzing Quantitative Empirical Studies***

| Criterion | Questions to Be Considered |
|---|---|
| **Theoretical Foundations** | What are theoretical foundations for the analysis?<br>Which theories were considered while constructing the indicator? |
| **Methodological Considerations** | How was the study under consideration designed?<br>What kind of data was used for the analysis and how was it collected? |
| **Dependent Variable/ Indicator** | What is the dependent variable in the analysis and how is it operationalized? |
| **Independent Variables (if any)** | What are the independent variables in the analysis and how are they operationalized? |
| **Relations of Institutional Spheres (or Dynamics) under Consideration** | Do researchers take into the consideration internal dynamics of each Triple Helix component (University, Industry, and Government), pairwise interaction dynamics (UI, UG, and IG), Triple Helix interactions (UIG) or all of them?<br>Is there any extra dynamics (fourth helix) included? |
| **Perspective on the Model used in the Study** | What perspective on the Triple Helix model is used for the analysis: neo-institutional, neo-evolutionary or the combination of both? |

## IV. REVIEW AND APPRAISAL OF THE QUANTITATIVE EMPIRICAL STUDIES

Twelve studies, considered in this paper, were aggregated into 6 groups and will be analyzed here in the following order:

1. Mutual (configurational) information as the Triple Helix dynamics indicator (6 studies);
2. φ-coefficients and partial correlation (1 study);
3. Contribution from embeddedness theory (1 study);
4. Vector Space model (1 study);
5. Patent-based Triple Helix indicators (1 study);
6. Regression models (2 studies).

### *IV.1. Mutual (Configurational) Information as the Triple Helix Dynamics Indicator*

As it was already stated in the conceptual part of this paper, there are two possible Triple Helix configurations among three elements – integrated (see Figure 3), which is characterized with positive overlap between three helices, and differentiated (see Figure 4) with no (or, in the other words, negative) overlap. This positive or negative overlap may be operationalized through the mutual information shared among the three helices in a system (Leydesdorff 2003), which can, therefore, measure the degree of integration and differentiation in the system's configuration in terms of relative frequencies of relations among overlapping helices at each moment of time (Leydesdorff, Dolfsma and van der Panne 2006, Leydesdorff and Sun 2009). The mutual information among three subsystems is, in this way, the analogue of covariation, however, calculated for three variables[18].

The more complex is the system – the more entropy is generated, bringing more uncertainty into it. The mutual information between three helices is supposed to reflect the sign and the size of such entropy (Leydesdorff 2003).

The question is then, how this mutual information can be measured. Since relations between the elements in the Triple Helix configuration may be considered as relative frequency distributions (Leydesdorff 2003, 2008), Shannon's mathematical theory of communication may be applied for calculations.

The Shannon-type probability information (or, in the other words, uncertainty in a distribution) for the one-dimensional variation can be represented in the following way:

$$H_i = -\sum_i p_i \, log_2 p_i \qquad (1),$$

where $H_i$ – Shannon-type information; $p_i$ – probability of an event in a general sample.

[18] Covariation is calculated only for two interacting variables.

Similarly, in case of two interacting variations:

$$H_{ij} = -\sum_{i}\sum_{j} p_{ij} log_2 p_{ij} \quad (2),$$

where $H_i$ – Shannon-type information for an interaction between two variables; $p_{ij}$ – probability of co-occurrence of two variables in a general sample.

Using two as the basis of the logarithm in formulas (1) and (2) means that uncertainty in a distribution is measured in the bits of information (Leydesdorff 2008). It should be mentioned here that Shannon-type information is dimensionless, and, therefore, independent of the size and any other characteristic of a system under study, which makes it applicable to any probability distribution. However, when researcher is trying to compare different systems using this method, it is necessary to specify the maximum entropy in each system under study to have a basis for normalization of results. This implies specification of these systems giving, therefore, a specific meaning to Shannon-type information.

The mutual information among two interacting subsystems is formalized through the transmission of uncertainty (T) using Abramson's formulas and Theil's decomposition algorithm (for more details, see Leydesdorff 2003, 2008):

$$T_{ij} = H_i + H_j - H_{ij} \quad (3),$$

where $T_{ij}$ – transmission of uncertainty between two variables; $H_i$, $H_j$ – Shannon-type information for single variables; $H_{ij}$ – Shannon-type information for an interaction between two variables.

As follows from equation (3), when two variables interact, the uncertainty in a system is increased by uncertainties of separate variables $(\mathrm{H_i} + \mathrm{H_j})$ and decreased through their interaction $(\mathrm{H_{ij}})$. Transmission of uncertainty for two variables is nonnegative and is only equal to zero, when two variables are exactly the same $(H_i + H_j = H_{ij})$.

Abramson (1963) has shown that in case of three interacting variables, mutual information between them is (Leydesdorff 2003, 2008):

$$T_{ijk} = H_i + H_j + H_k - H_{ij} - H_{ik} - H_{jk} + H_{ijk} \quad (4),$$

where $T_{ijk}$ – transmission of uncertainty between three variables; $H_i$, $H_j$, $H_k$ – Shannon-type information for single variables; $H_{ij}$, $H_{ik}$, $H_{jk}$ – Shannon-type information for interactions between two variables; $H_{ijk}$ – Shannon-type information for interaction between three variables.

Summarizing formula (4), while bilateral relations tend to reduce the uncertainty in a system, trilateral relations are supposed to increase it. In terms of integrated and differentiated configurations of a system (see above), this means that integrated system with positive overlap (Figure 3) is supposed to be less certain than differentiated system with negative overlap. In the other words, negative overlap among the helices brings negative entropy in a system, making it more certain and giving it more ability for self-organization. Therefore, when transmission of uncertainty becomes more negative over time, one can talk about increasing systemness, and vice versa.

Besides, using the formula (4) it is possible to analyze the contribution of each element (individual, bilateral and trilateral relations) towards the uncertainty in the current system's configuration. This sheds some light on system's structural characteristics.

To date, this method, developed by Leydesdorff, has been used in six empirical studies, which can be divided into 3 sub-groups: (1) measuring the knowledge-base of an economy in terms of Triple Helix of university, industry and government (Park and Leydesdorff 2010; Park, Hong, Leydesdorff 2005); (2) measuring the knowledge-base of an economy in terms of Quadruple Helix of university, industry, government and international co-authorship relations (Leydesdorff and Sun 2009); and, (3) measuring the knowledge-base of an economy in terms Triple Helix of technology, organization and territory (Leydesdorff, Dolfsma and van der Panne 2006; Leydesdorff and Fritsch 2005; Lengyel and Leydesdorff 2011). In the following, I will briefly discuss the main features of each approach.

***Measuring the Knowledge-Base of an Economy in terms Triple Helix of University, Industry and Government***

This group of studies is represented by the comparative study of South Korean and Dutch knowledge bases (Park, Hong, Leydesdorff 2005) and the study of longitudinal trends in the university-industry-government relations in South Korea (Park and Leydesdorff 2010).

As the theoretical framework both studies are employing a combination of neo-institutional and neo-evolutionary perspectives on the Triple Helix model. On the one hand, authors use institutional actors (university, industry and government) as the elements of the Triple Helix. On the other hand, relations among them are analyzed from the point of arising synergies between helices and emergence of a hypercycle, which is supposed to bring systemness into an economy.

Both studies are based on bibliometric analysis of publications in the Science Citation Index. In order to calculate mutual information in the national innovation systems of the Netherlands and South Korea all the publications with at least one Korean and Dutch address were collected and then attributed to the one of the institutional sector (university, industry or government) or their bilateral and trilateral interaction[19]. The result of such redistribution among different categories for both countries is presented in the Table 3.

***Table 3. Publications in South Korea and the Netherlands in 2000 and 2002***

| Country | Year | Number | % titles retrieved | UI | UG | IG | UIG | Univ | Ind | Govt |
|---|---|---|---|---|---|---|---|---|---|---|
| All | 2000 | 676511 | 93.3 | 16270 | 108919 | 4359 | 5201 | 543123 | 41242 | 232096 |
| | 2002 | 683222 | 93.6 | 17095 | 116782 | 4626 | 5664 | 556370 | 41840 | 234843 |
| South Korea | 2000 | 12038 | 98.3 | 351 | 2341 | 87 | 91 | 10345 | 676 | 3978 |
| | 2002 | 14931 | 98.7 | 533 | 3115 | 118 | 183 | 13163 | 996 | 4904 |
| Netherlands | 2000 | 18357 | 95.3 | 372 | 4482 | 106 | 259 | 16379 | 863 | 6593 |
| | 2002 | 17865 | 95.1 | 328 | 4663 | 78 | 307 | 15927 | 859 | 6762 |

*Source: Park, Hong and Leydesdorff 2005, p. 14*

After collecting and preparing all data for the analysis, mutual information among the three institutional sectors is calculated using formula (4). Park, Hong and Leydesdorff (2005) claim that South Korean economy shows more systemness than the Dutch one in both 2000 and 2002, since transmission of uncertainty (mutual information) was more negative. However, both systems are less integrated than the world's economy in general (Table 4).

***Table 4. Mutual Information of University-Industry-Government in South Korea and the Netherlands in 2000 and 2002***

| Country | Year | T(uig) in mbits |
|---|---|---|
| All | 2000 | –77.0 |
| | 2002 | –70.7 |
| South Korea | 2000 | –40.1 |
| | 2002 | –33.7 |
| Netherlands | 2000 | –25.4 |
| | 2002 | –32.8 |

*Source: Park, Hong, Leydesdorff 2005, p. 14*

In terms of knowledge base this means that there are better prerequisites for the knowledge production in South Korea since there is better networking among the three institutional spheres under consideration. However, it is worth mentioning that while the trend in the Netherlands was towards bigger systemness (from -25.4 mbits in 2000 to -32.8 mbits in 2002), in South Korea it was the opposite.

[19] In this way, if the publication is made through, for example, collaboration of university and industry, it is attributed only to the UI category and is not considered in the individual output of university and industry categories.

The same procedures were used for the study of longitudinal trends in South Korean economy; however, the period under analysis was much larger (from 1972 to 2006). It has been illustrated that the trend of systemness stabilized after 2002 and mutual information among three helices remained at the same level for the period of 2002-2006. Besides, it has been shown that reformation of South Korean research sector (universities and research institutions) and introduction of new science and technology policy in 1970s-1980s had a positive impact on systemness of South Korean economy.

Though being a convenient method for comparing different national innovation systems and tracing networking dynamics, this approach has a couple of limitations. First of all, it is not necessarily that scientific output (published articles) is the best approximation for innovation output in an economy. Besides, collaboration between, for example, university and industry may not result in a publication, however, such collaboration may nevertheless add to systemness of an economy. Therefore, calculations in this case are approximate. However, these issues are general problems of bibliometric method of analysis and are not specific just for these particular studies.

***Measuring the Knowledge-Base of an Economy in terms of Quadruple Helix of University, Industry, Government and International Co-Authorship Relations***

The discussion on the possible extension of the Triple Helix model to four or more dimensions resulted in a search for new variables that may be included into the analysis. The study of Leydesdorff and Sun (2009) is one of the steps in this way. They suggested adding international co-authorship relations into the consideration along with cross-sectoral relations at a national level. The motivation for this step is that in the globalizing world formation of international research teams became one of the major trends in recent years (Leydesdorff and Sun 2009).

Methodological and theoretical foundations for the study were the same as in the previous group of studies. However, inclusion of fourth dimension into the model required extension of formula (4) by including quadrilateral relations into the consideration[20]:

$$T_{uigf} = H_u + H_i + H_g + H_f - H_{ui} - H_{ug} - H_{ig} - H_{uf} - H_{if} - H_{gf} + H_{uig} + H_{uif} + H_{ugf} + H_{igf} - H_{uigf} \quad (5),$$

where $T_{uigf}$ – mutual information between four variables; $H_u$, $H_i$, $H_g$, $H_f$ – single variables' Shannon-type information; $H_{ui}$, $H_{ug}$, $H_{ig}$, $H_{uf}$, $H_{if}$, $H_{gf}$, – Shannon-type information for interactions between two variables; $H_{uig}$, $H_{uif}$, $H_{ugf}$, $H_{igf}$, – Shannon-type information for interactions between three variables; $H_{uigf}$ – Shannon-type information for interaction between four va-

[20] Following Leydesdorff and Sun (2009) I will use "f" index for international co-authorship.

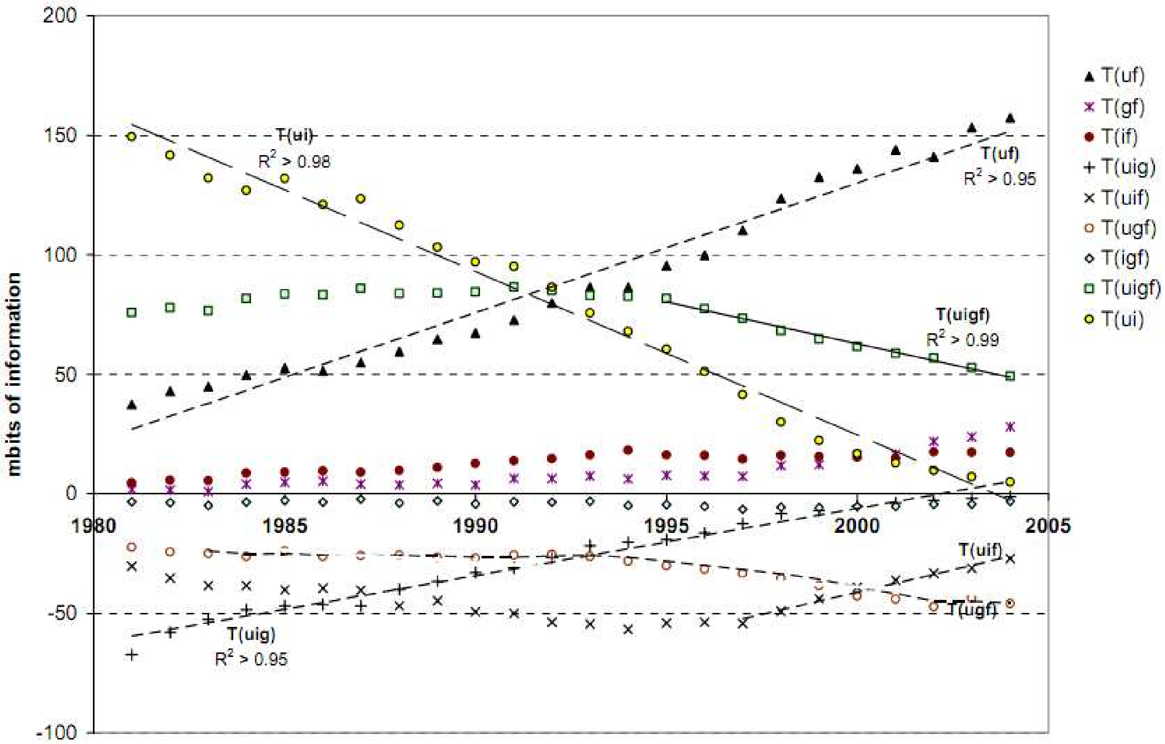
riables.

The question is, however, if it is reasonable to follow the logic of the mathematical theory of communication – do quadrilateral relations really reduce the uncertainty in the system? The authors do not give the answer to that question. Therefore, this issue requires further studying.

The data was collected in the same way as in the study of cross-sectoral relations at a national level (see above). However, seven new variables have been created in order to capture the effect of international co-authorship (UF, IF, GF bilateral relations; UIF, UGF, IGF trilateral relations; UIGF quadrilateral relations)[21].

The full results of the analysis are presented in the Figure 8.

***Figure 8. Mutual Information for Two, Three and Four Dimensions in Japan in 1981-2004***




*Source: Leydesdorff and Sun 2009, p. 783*

Looking at the values of $T_{uig}$ and $T_{uigf}$, it is possible to conclude that while cross-sectoral relations between university, industry and government were developing in the way of bringing negative effect on economy's systemness (rising trend for $T_{uig}$ line), international co-authorship relations, being in the process of integration into Japanese national innovation system, brought more self-organization and systemness into it (falling trend for $T_{uigf}$).

[21] It is necessary to mention, that not all international publications were considered – only those publications were included, which contained at least one Japanese address in the Science Citation Index. This was made because it would be strange to assume that all international publications are relevant for Japanese innovation system.

It is necessary to mention here that if we calculated the values of $T_{ij}$, $T_{ijk}$ not taking international co-authorship relations into the consideration we would have different values, because of different bases for normalization of the total number of publications.

The above given comments imply some limitations for the mutual information as the indicator of Triple (Quadruple) Helix dynamics. First of all, it is impossible to directly compare the situations when we use different bases for normalization. For example, $T_{Uig}$ calculated for the same country in the cases of Triple Helix and Quadruple Helix will have different values (and may even have different signs). This limitation automatically leads to the second one. Using the same methodology as in previously considered empirical studies makes it impossible to develop the scale of $T_{ij}$, $T_{ijk}$ and $T_{ijkl}$, which would reflect borders for 'good' or 'bad' levels of bilateral, trilateral and quadrilateral relations. Instead, it is only possible to look at their dynamical aspect. Besides, in this case limitations of bibliometric analysis should be considered as well.

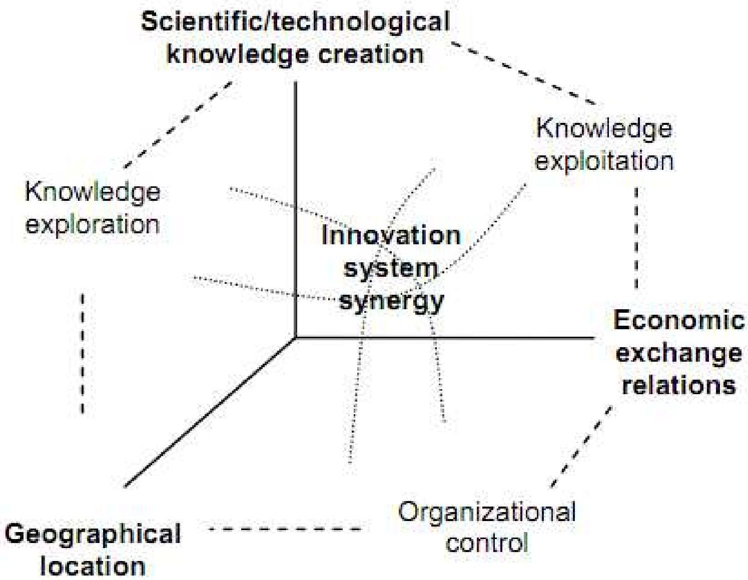
***Measuring the Knowledge-Base of the Economy in terms Triple Helix of Technology, Organization and Territory***

The other way to look at the Triple Helix model from the neo-evolutionary (functional) perspective is to consider Storper's (1997) 'holy trinity' of geography, technology and organization, interrelations among which are considered to shape the regional economies (Lengyel and Leydesdorff 2011; Leydesdorff, Dolfsma and van der Panne 2006). The 'holy trinity' in this way is another operationalization of functions of an innovation system: wealth generation (knowledge exploitation), knowledge exploration and normative control (Figure 9). The research question in this case is to what extent the interrelations between geography, technology and organization contribute to the development of a regional economy (Leydesdorff and Fritsch 2006).

To date this approach has been employed in the empirical studies of innovation systems of the Netherlands (Leydesdorff, Dolfsma and van der Panne 2006), Germany (Leydesdorff and Fritsch 2006) and Hungary (Lengyel and Leydesdorff 2011).

The following proxies have been used for the operationalization of each of the 'holy trinity' elements: (1) firm size as a proxy for organizational structure (it is supposed that the more employees the firm has – the more complex is its structure); (2) the three-digit code of an industry as a proxy for technology (firms in different industries are supposed to have different technological knowledge bases); and, (3) geographical address as a proxy for geography (Leydesdorff, Dolfsma and van der Panne 2006). The data used in all studies consist of records in the national registers of firms[22].

***Figure 9. Functional Synergy in Innovation System***




*Source: Lengyel and Leydesdorff 2011, p. 681*

After collecting all the data, the Shannon-type probability information is calculated using the formulas (1)-(3) for each of the regions inside the country[23]. In case of the Netherlands calculations resulted in the following values (Table 5).

***Table 5. Shannon-type Information for Three Dimensions and Their Combination***

| | $H_{Geography}$ | $H_{Technology}$ | $H_{Organization}$ | $H_{GT}$ | $H_{GO}$ | $H_{TO}$ | $H_{GTO}$ | $N$ |
|---|---|---|---|---|---|---|---|---|
| NL | 6.205 | 4.055 | 2.198 | 10.189 | 8.385 | 6.013 | 12.094 | 1131668 |
| % $H_{max}$ | 95.6 | 69.2 | 61.3 | 82.5 | 83.2 | 63.7 | 75.9 | |
| Drenthe | 2.465 | 4.134 | 2.225 | 6.569 | 4.684 | 6.039 | 8.413 | 26210 |
| Flevoland | 1.781 | 4.107 | 2.077 | 5.820 | 3.852 | 6.020 | 7.697 | 20955 |
| Friesland | 3.144 | 4.202 | 2.295 | 7.292 | 5.431 | 6.223 | 9.249 | 36409 |
| Gelderland | 3.935 | 4.091 | 2.227 | 7.986 | 6.158 | 6.077 | 9.925 | 131050 |
| Groningen | 2.215 | 4.192 | 2.220 | 6.342 | 4.427 | 6.059 | 8.157 | 30324 |
| Limburg | 2.838 | 4.166 | 2.232 | 6.956 | 5.064 | 6.146 | 8.898 | 67636 |
| N-Brabant | 3.673 | 4.048 | 2.193 | 7.682 | 5.851 | 6.018 | 9.600 | 175916 |
| N-Holland | 3.154 | 3.899 | 2.116 | 6.988 | 5.240 | 5.730 | 8.772 | 223690 |
| Overijssel | 2.747 | 4.086 | 2.259 | 6.793 | 5.002 | 6.081 | 8.749 | 64482 |
| Utrecht | 2.685 | 3.956 | 2.193 | 6.611 | 4.873 | 5.928 | 8.554 | 89009 |
| S-Holland | 3.651 | 3.994 | 2.203 | 7.582 | 5.847 | 5.974 | 9.528 | 241648 |
| Zeeland | 1.802 | 4.178 | 2.106 | 5.941 | 3.868 | 6.049 | 7.735 | 24339 |

*Source: Leydesdorff, Dolfsma and van der Panne, p. 188*

After that transmissions of the uncertainty are calculated for bilateral and trilateral relations in different regions. However, in order to compare the values of transmissions and their contributions to a national system of innovation it is necessary to perform the normalization of the results. Size of a region (in terms of number of registered firms) is used as a basis for nor-

[22] In all three countries the registration in the national register is obligatory for the companies.

[23] The aggregation of the regions may be performed for different levels (NUTS-1, NUTS-2, etc.).

malization:

$$\Delta T_{gto_i} = T_{gto_i} * {}^{n_i}/_{N} \quad (6),$$

where $\Delta T_{gto_i}$ – normalized regional transmission of uncertainty; $T_{gto_i}$ – originally calculated regional transmission of uncertainty; $n_i$ – the number of firms in a region; $N$ – total number of firms in all regions ($N = \sum n_i$).

When normalized regional transmissions of uncertainty are found, one can also calculate the so-called in-between-regions transmission of uncertainty:

$$T_0 = T_{gto} - \sum_i \Delta T_{gto_i} \quad (7),$$

where $T_0$ - in-between-regions transmission of uncertainty; $T_{gto}$ – transmission of uncertainty on the national level; $\sum_i \Delta T_{gto_i}$ – sum of normalized transmissions of uncertainty for all regions in a country.

When $T_0$ is below zero, it means that regions interact between each other so that the uncertainty on a national level is reduced. In the other words, negative $T_0$ reflects regional integration at the national level or the emergence of 'real' national innovation system.

The results of calculations for the Netherlands are presented in Table 6.

***Table 6. Mutual Information of Geography, Technology and Organization Decomposed at a Regional Level***

| | $\Delta T_{GTO}$ (=$n_i \times T_i/N$) in millibits of information | $n_i$ |
|---|---|---|
| Drenthe | −1.29 | 26210 |
| Flevoland | −0.55 | 20955 |
| Friesland | −1.79 | 36409 |
| Gelderland | **−4.96** | 131050 |
| Groningen | −1.20 | 30324 |
| Limburg | −1.96 | 67636 |
| N-Brabant | **−5.56** | 175916 |
| N-Holland | **−3.28** | 223690 |
| Overijssel | −1.98 | 64482 |
| Utrecht | −1.86 | 89009 |
| S-Holland | **−5.84** | 241648 |
| Zeeland | −0.83 | 24339 |
| Sum ($\sum_i P_i T_i$) | −31.10 | 1131668 |
| $T_0$ | **−2.46** | |
| NL | −33.55 | $N$=1131668 |

*Source: Leydesdorff, Dolfsma and van der Panne, p. 190*

Negative in-between-regions transmission of uncertainty testifies that Dutch innovation system is integrated at the national level. In the other words, Dutch regions brought together form the national system of innovation. The cases of Germany and Hungary, however, illustrate the failing integration at a national level. German system of innovation is integrated on the level of *Länder* (Leydesdorff and Fritsch 2006), which is normal for the large state with federal organization of the territory. In case of Hungary, it is possible to distinguish three subnational innovation systems: north-western part of the country integrated to the European system, central part with dominance of private R&D initiatives, and southern part, where government is a regional innovation organizer[24] (Lengyel and Leydesdorff 2011).

Besides looking at an aggregated level, one can also perform the sectoral decomposition of the results, using the same procedures as above, but for each of industrial groups (in accordance with the three-digit codes). This would help to understand the contribution of different sectors to development of the knowledge base of an economy.

Not going deep into the details it is worth mentioning the main results of sectoral decomposition, which were confirmed for all three countries using this methodology (cited from Lengyel and Leydesdorff 2011):

- the knowledge base of an economy is driven primarily by medium-tech manufacturing (and by high-tech manufacturing to the less extent);
- high-tech services are contributing to the structuring of the knowledge base;
- the knowledge intensive services, which are not high-tech do not have a strong effect on a regional economy.

It may be interesting in the future to (1) test these ideas for the other countries; (2) confirm these ideas for the Netherlands, Germany and Hungary using the other methodology (in order to justify both Triple Helix as the theoretical model and mutual information as a method of quantitative analysis).

The main limitation of using mutual information approach to the Storper's model is that operationalization of the variables may lead to a situation, when the factual data is not measuring what is supposed to be measured. Choosing the size of a firm as a proxy for organizational structure may be not correct since bigger number of employees does not necessarily (1) lead to the more complex organization of the company, and (2) imply more complexity in the economic exchange relations. In the other aspects, however, this approach seems to be the good instrument for comparing different regional innovation systems and analyzing their contribution to a national system of innovation.

[24] Such differences between regions may be partly explained by the fact that Hungary is still in the process of transition (1) from centrally planned to market economy; and, (2) from the production-based to the knowledge-based economy.

*IV.2. φ-Coefficients and Partial Correlation as the Indicators of the Triple Helix Dynamics*

Though mutual information has proved to be useful approach, Sun and Negishi (2010) claim that it is not widely used due to some theoretical drawbacks (e.g. extension to four variables is not always clear) and the fact that not all researchers are familiar with mathematical theory of communication, which makes using mutual information complicated. Instead, they suggest using φ-coefficients and partial correlation, which are easier in terms of calculations and explanations.

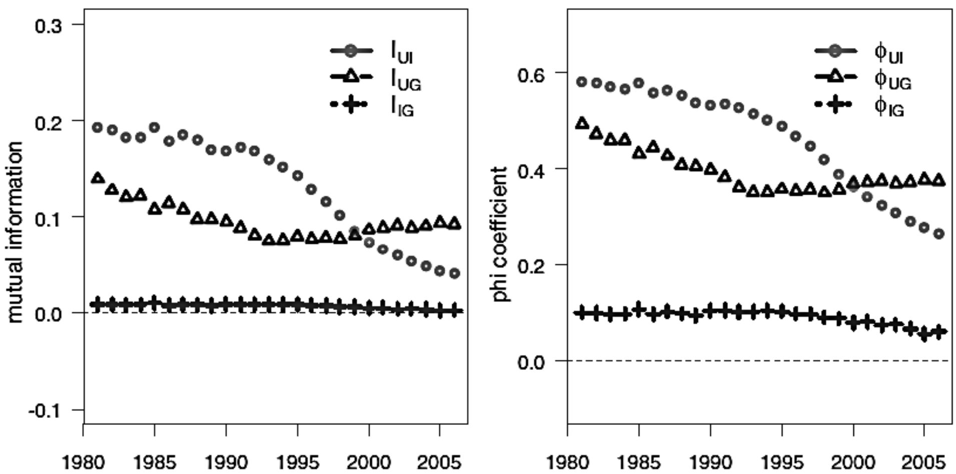
φ-coefficient is used for the analysis of bilateral relations. In its numerical value it is the analogue of Pearson correlation coefficient:

$$\varphi_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (8),$$

where $x_i$, $y_i$ – individual values of variables x and y; $\bar{x}$, $\bar{y}$ – mean values of variables x and y.

Using the same data and perspective on the Tripe Helix model as Leydesdorff and Sun (2009), Sun and Negishi (2010) have shown that φ-coefficient reflects the same dynamics as mutual information among two variables (Figure 10).

***Figure 10. Mutual Information and φ-Coefficients***




*Source: Sun and Negishi 2010, p. 681.*

Since φ-coefficient unlike mutual information is limited between -1 and 1 ($-1 \leq r_{xy} \leq 1$), using it for the analysis of bilateral relations may provide more detailed information about the strength of relations. However, when it comes to the analysis of trilateral and, in general, n-lateral relations, this indicator is useless.

In case of three variables in the system, Sun and Negishi (2009) suggest using the so called partial correlation coefficient (formula (9)), which is corresponding to partial mutual information indicators (formula (10)).

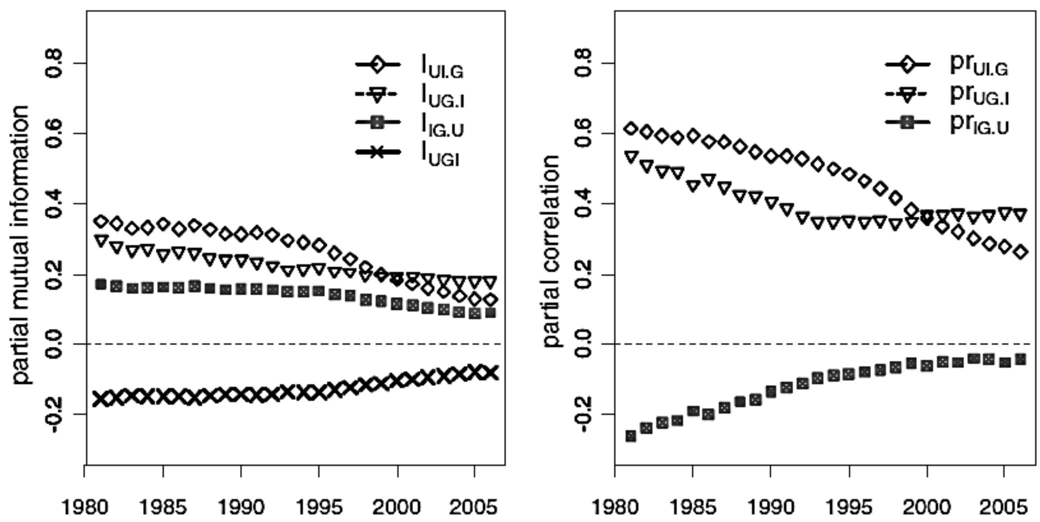
$$r_{xy|z} = \frac{r_{xy} - r_{xz}r_{yz}}{\sqrt{1 - r_{xz}^2}\sqrt{1 - r_{yz}^2}} \quad (9)$$

$$T_{xy|z} = T_{xy} - T_{xyz} \quad (10),$$

where $r_{xy|z}$ – partial correlation coefficient; $T_{xy|z}$ – partial mutual information; $r_{ij}$ – correlation coefficient between two variables; $T_{xy}$ – transmission of uncertainty between two variables; $T_{xyz}$ – transmission of uncertainty between three variables.

Both indicators reflect the degree of relations between two variables (x and y), when the effect of the third variable (z) is removed. In terms of evolutionary Triple Helix, this means that both indicators measure the synergy between variables x and y, when function z acts as a selection environment. The calculations based on the same dataset reveal the following dynamics (Figure 11):

***Figure 11. Partial Mutual Information and Partial Correlation***




*Source: Sun and Negishi 2010, p. 682.*

We can see that both coefficients reflect the same dynamics for all relations (the line $pr_{ig|u}$ is the mirrored reflection of $I_{ig|u}$, which is normal because mutual information between two variables is always no less than zero). However, it is still impossible to calculate partial correlation for 'full' trilateral relations between university, industry and government, which can distort conclusions about the situation in a national innovation system.

In case of four or more variables it is also possible to calculate the partial correlation coefficients. However, this implies some more difficult calculations. Since in this paper I have no intention to go deep into the mathematical procedures, I will not discuss it here. Though, it is worth mentioning that the general procedure is exactly the same.

Summing up the above stated, φ-coefficients and partial correlation may be used as an easier in terms of calculations analogue of mutual information. However, these indicators do not entirely reveal deep nature of trilateral relations in the Triple Helix model and, therefore, lose to mutual information in terms of explanation power.

### *IV.3. Contribution from Embeddedness Theory*

Totally different approach toward measuring Triple Helix relations was suggested by Villanueva, Molas-Gallart and Esteve (2006). They put forward the Triple Helix notion that in the knowledge based economy innovation is produced through the complex pattern of relations between university, industry and government. However, instead of looking at an aggregated level of nations or regions, they concentrate on the level of individual researchers and their networks. The main idea behind their study is that the nature and the structure of the researchers' informal networks (so-called 'relational embeddedness') determine their research output in terms of publications.

Villanueva, Molas-Gallart and Esteve (2006) distinguish two characteristics of the researcher's network: *degree of embeddedness* and *nodal heterogeneity*. Some comments should be made here before proceeding to the quantitative aspects of the study.

In terms of embeddedness three types of networks are distinguished: overembedded, integrated and underembedded (Villanueva, Molas-Gallart and Esteve 2006).

*Overembedded networks* are characterized by existence of only strong relations of the researcher with the other actors. Such relations are based on trust, reciprocity and high frequency of interactions. *Underembedded networks* are based on weak ties of the researcher with the other actors, which are not based on trust and reciprocity and do not have any stable frequency of interaction. *Integrated networks* are those, which combine both strong and weak relational ties. The first hypothesis for the study was that integrated networks lead to higher research output of a scientist[25] (Villanueva, Molas-Gallart and Esteve 2006). The relations are also distinguished between intra-academia and non-academic ones.

The degree of embeddedness is calculated using the following formula:

$$DE = \frac{ST_u + ST_{ou}}{TT} \qquad (11),$$

where *DE* – degree of embeddedness, $ST_U$ – number of strong ties in a university sector, $ST_{OU}$ – number of strong ties outside academia, *TT* – total number of ties of a researcher.

[25] The idea behind that hypothesis is that overembedded networks are limited in the number of people in the network and, therefore, in the flows of information. On the other hand, underembedded networks, being infrequent and not based on trust, limit the ability of a researcher to extract some useful information from them. The mix of the relations seems to overcome the limitations and strengthen the advantages of both types of networks.

*Nodal heterogeneity* refers to the "variation in the mix of direct contacts in the social networks of individuals" (Villanueva, Molas-Gallart and Esteve 2006, p. 8). Two factors of heterogeneity are considered: geographic location (local, national and international contacts) and institutional factor (contacts inside and outside academia). The hypothesis is that the more heterogeneous is a researcher's network, the higher is his/her research output. The degree of heterogeneity is calculated using the Ruef entropy measure:

$$NH = -\sum_{i=1}^{n}\left(\frac{\log y_i}{\log n}\right) * y_i \quad (12),$$

where *NH* – degree of nodal heterogeneity, *n* – number of social categories considered ($1 \leq n \leq 5$), $y_i$ – proportion of contacts within each category.

As for the research output, it is calculated in the following way:

$$RO = NatConf + 2 * IntConf + 3 * (NatArt + 2 * NatIndArt) + 4 * (IntArt + 2 * IntIndArt) + 5 * Book/Authors \quad (13),$$

where *NatConf* – number of papers presented at national research conferences, *IntConf* – number of papers presented at international research conferences, *NatArt* – number of articles published in national journals, *NatIndArt* – number of articles published in national indexed journals, *IntArt* – number of articles published in international journals, *IntIndArt* – number of articles published in international indexed journals, *Books/Authors* – number of published books corrected for the number of authors.

As follows from (13) different types of publications are given different weights depending on their supposed level of influence and effort spent on a preparation of a publication. However, this is not clear from this methodology, how is a publication counted, if it was, for example, both presented at a conference and published in a national journal. I would suggest that only the highest level should be considered (in this case, publication in a journal). Villanueva, Molas-Gallart and Esteve (2006), however, do not make this point clear.

The data for the study was collected through sending questionnaires to the researchers in the University of Valencia, where they were asked questions concerning their networks[26]. After collecting the data Villanueva, Molas-Gallart and Esteve (2006) used cluster analysis for distinguishing the groups of researchers in accordance with their networks' characteristics. The results of the study confirmed both hypotheses (influence of embeddedness and nodal heterogeneity on the research output) (see Tables 7 and 8).

[26] The total final number of the questionnaires included into the study is 64.

***Table 7. Degree of Embeddedness and Research Output***

| | N | Degree of embeddedness | Research output means |
|---|---|---|---|
| Group 1 - Overembedded network | 11 | .9505 | 3.1482 |
| Group 2 - Integrated network | 31 | .6250 | 8.3010 |
| Group 3 - Underembedded network | 22 | .2705 | 5.0873 |

*Source: Villanueva, Molas-Gallart and Esteve 2006, p. 14*

As follows from Table 7, integrated network indeed creates the best opportunities for producing larger research output. T-test at a=0,1 confirms the significance of differences between the groups.

***Table 8. Nodal Heterogeneity and Research Output***

| Groups | N | Geographic diversity | Institutional diversity | Total heterogeneity | Research output means |
|---|---|---|---|---|---|
| 1 | 9 | .000 | .000 | 0.00 | 1.5044 |
| 2 | 21 | .683 | .096 | 0.39 | 6.4829 |
| 3 | 19 | .517 | .882 | 0.70 | 6.1674 |
| 4 | 15 | .847 | .793 | 0.82 | 9.1347 |

*Source: Villanueva, Molas-Gallart and Esteve 2006, p. 16*

As follows from Table 8, the more diverse is a researcher's network the more is his/her research output. The T-test, however, confirms the significance of the difference only between the first (homogenous) group and all others. So the final conclusion is that homogenous network tends to reduce a researcher's output. One more conclusion is that institutional diversity seems to be less important than the geographic one, however, is still contributing positively to research output.

Summing up, the procedure developed by Villanueva, Molas-Gallart and Esteve (2006) is a good instrument for analyzing the individual output of a researcher taking into consideration the Triple Helix relations in their neo-institutional perspective. Though it was not presented in the paper, using the same procedure it is possible to divide outside-academia relations to researcher-industry, researcher-government, researcher-industry-government relations, which would shed more light on the structure of relations and importance of Triple Helix linkages for the work of a researcher. Besides, one can look at a more aggregated level of universities as a whole and their relations with companies and governmental agencies. Moreover, it is also possible to extrapolate the same procedure onto the spheres of industry and government. However, this would imply difficulties in terms of collecting relevant data.

### *IV.4. Vector Space Model: Graphical Representation of the Triple Helix Relations*

One more attempt to analyze the Triple Helix relations on less aggregated level is the study performed by Ortega Priego (2003), who looked at biology and biomedicine research centres of two national research councils: Consejo Superior de Investigaciones Cientificas in Spain and Max Plank Gesellschaft in Germany. Methodologically, he based his study on the Vector Space model, which considers variables as vectors and allows analyzing relations between different variables as a degree of their multiple occurrences in a data sample.

Generally, the Vector Space model characterizes the vector with the frequencies of occurrences of particular characteristics (Ortega Priego 2003):

| | i | j | N |
|---|---|---|---|
| $V_1$ | $F_{1i}$ | $F_{1j}$ | $F_{1N}$ |
| $V_2$ | $F_{2i}$ | $F_{2j}$ | $F_{2N}$ |

where $V_1$, $V_2$ – vectors; $F_i$, $F_j$, $F_N$ – frequencies of occurrences of characteristics *i, j, N* respectively.

The degree of similarity between different vectors is then calculated using the formula (14).

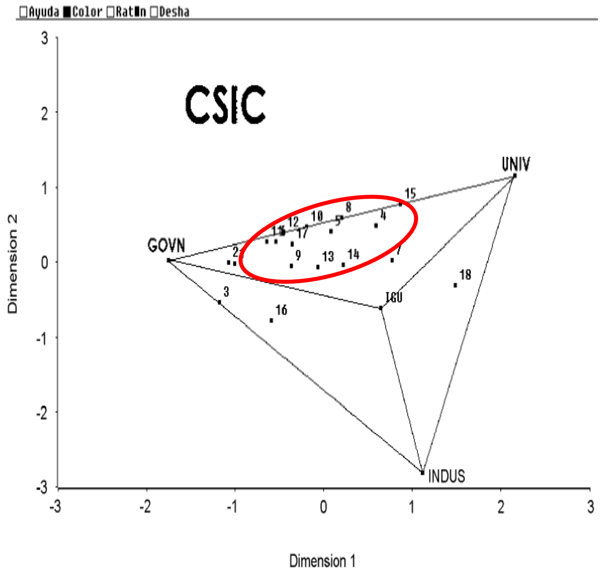
$$DS(V_1;V_2) = \frac{\sum F_1 F_2}{\sqrt{\sum F_1^2 \sum F_2^2}} \quad (14),$$

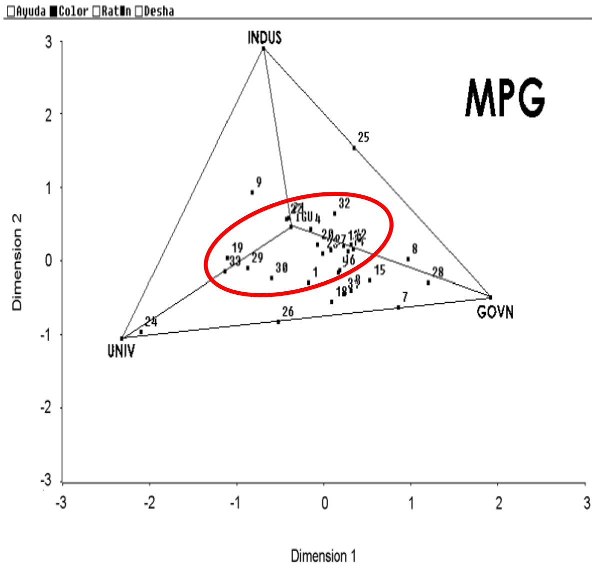
where $DS(V_1;V_2)$ – degree of similarity between vectors $V_1$, $V_2$; $F_i$ – requencies of multiple occurrences of characteristic *i*.

For the analysis of Triple Helix relations Ortega Priego (2003) used the webometric approach, studying the web-pages of 33 research centres in Max Plank Gesellschaft and 18 research centres in Consejo Superior de Investigaciones Cientificas. Coordinates of individual vectors of each research centre were operationalized through percentage of outlinks from research centre web-page towards academia, industrial and governmental agencies, which were retrieved using CyberSpyder Link Test software. Besides, four standard vectors were specified: University (1;0;0), Industry (0;1;0), Government (0;0;1) and UIG intermediate vector (½;½;½).

On the next step, the degree of similarity is calculated between vectors of research centres and standard vectors; and obtained similarities are transformed into distances ($D_i$=1-$DS_i$). Using calculated distances, all vectors were positioned on the coordinate field, using the multidimensional scaling (MDS) procedure (Ortega Priego 2003, p. 435). The results of the MDS for two national research councils are presented in Figure 12 (a and b).

*Figure 12. MDS Map for Consejo Superior de Investigaciones Cientificas (a) and Max Plank Gesellschaft (b)*




(a) (b)

*Source: Ortega Priego 2003, pp. 436-437.*

As follows from Figure 12 (a), research centres in *Consejo Superior de Investigaciones Cientificas* fail to establish Triple Helix relations with industry and government, since most of the vectors are situated along university-government axis, which means that relations between them are solely bilateral. In the other words, Spanish research centres are not fitting the Triple Helix model in terms of forming trilateral relationships.

As for the German case, Figure 12 (b) demonstrates that most of research centres in Max Planck Gesellschaft are located around the intermediate standard vector. This reflects the fact that they show a bigger tendency toward Triple Helix relations.

To sum up, the Vector Space model along with multidimensional scaling technique provides the instrument for analyzing Triple Helix relations from the institutional perspective using graphical positioning approach. This method provides the reader with easy understandable comprehensive results, which are also easy to interpret. However, this method is exposed to the general weaknesses of the webometric analysis. First of all, there is no guarantee that co-publications on the page of a research centre are really reflecting the interaction or collaboration with the other actors. Besides, even if such collaboration is established, it is not necessarily the case that this collaboration will lead toward innovation. Nevertheless, this method may be considered as the good basis for the future research.

### *IV.5. Patent-Based Triple Helix Indicators*

Number of patents issued for a single country, industry, university, etc. has been often used for reflecting their innovation capability. Meyer, Siniläinen and Utecht (2003) tried to apply this indicator using the Triple Helix theoretical framework in its institutional perspective and the model of entrepreneurial university to Finnish national innovation system.

Using the data from US Patent and Trademark Office, Meyer, Siniläinen and Utecht (2003) collected the information on 530 patents granted to 285 Finnish university researchers between 1986 and 2000. After collecting the information on patents, Meyer, Siniläinen and Utecht (2003) suggested six indicators, which are supposed to reflect the structure and the nature of an environment in which Triple Helix relations are developing.

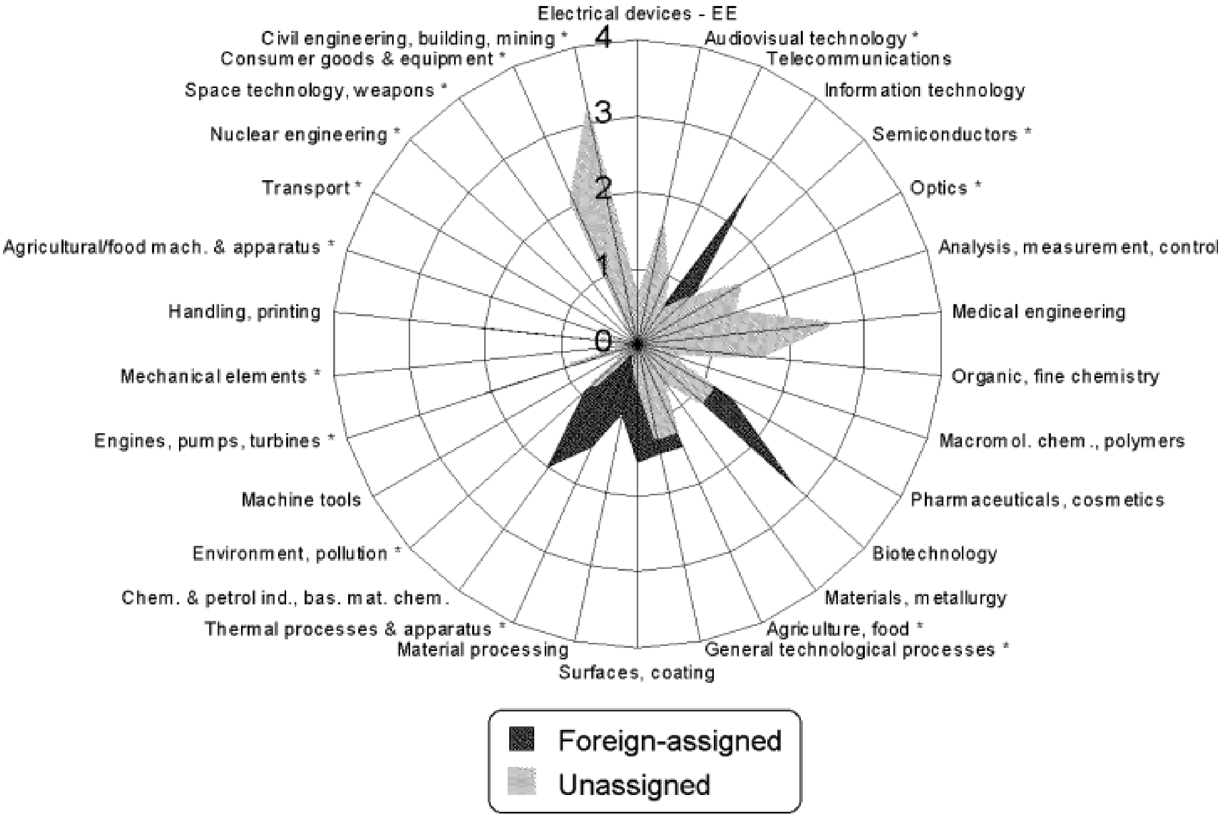
The first indicator is *Total Inventive Activity of the Universities*, which is calculated as a share of patents granted to university researchers in the total number of patents granted to a country. In case of Finnish patents issued between 1986 and 2000 this indicator is equal to eight percent (Meyer, Siniläinen and Utecht 2003, p. 331), reflecting that university researchers are playing an important role in Finland in terms of science-technology linkages. In general, total inventive activity reflects the potential for academic entrepreneurship.

The second suggested indicator is *Concentration of Patents*, which reflects the shares of particular universities in the total number of university-granted patents. In case of Finland, three quarters of all university-based patents are granted to four largest universities (Meyer, Siniläinen and Utecht 2003, p. 332). This indicator may be useful for defining the main actors which can develop into entrepreneurial universities and, in general, specifying main regional nodes of academic entrepreneurship.

The other two indicators, namely the *Share of Patents Utilized in Start-Up Companies* and *Share of Patents Utilized in Large Companies and Established SMEs*, are supposed to indicate the degree, to which academic entrepreneurship or university-industry relations act as drivers for applied research at universities. The bigger is the share of patents utilized in start-up companies – the more entrepreneurial orientation a university is supposed to have. On the other hand, the more patents are utilized in large companies – the more collaborative are the research activities in the universities. Of course, such indicators are disputable proxies for entrepreneurial orientation of a university. However, they can give a general idea about the nature of university-industry relations prevailing at a concrete university.

Finally, Meyer, Siniläinen and Utecht (2003) suggest analyzing the *Share of Unassigned and Foreign-Assigned Patents* granted to university researchers. Using such indicators would help to identify the research activities that are less or even not demanded in the national (or, regional) innovation system. This may be done on the level of a whole system or the level of particular industries. For example, the results for the Finnish case are presented in Figure 13.

***Figure 13. Share of Unassigned and Foreign-Assigned Patents in the Total Number of Patents***




*Source: Meyer, Siniläinen and Utecht 2003, p. 336*

All in all, these indicators allow understanding the general structure if university-industry relations and the role of academic entrepreneurship in the national innovation system. However, limiting the analysis only to these six indicators would not give the full picture of the Triple Helix relations. First of all, the contributions of the government are not analyzed at all. Besides, some other types of university-industry collaboration are not taken into the consideration: funding of a research, usage of university laboratories by industrial researchers and vice versa, etc. Besides, these indicators have all general weaknesses of patenting data. Main shortcoming of such indicators is that number of patents characterizes mostly inventions rather than real innovations since not all the patents are commercialized. Therefore, using number of patents as the indicator of academic entrepreneurship may not always be suitable. Besides, not all new technologies are supposed to be patented, especially when it comes to process innovations.

Therefore, using this method it is necessary to always remember limitations of patenting data. Besides, in order to reflect the whole variety of Triple Helix relations the method should be extended by taking into the consideration university-government and industry-government relations. This, on the other hand, would require the huge work on data collection and analysis which can become too time-consuming activity.

### *IV.6. Regression Models*

In this final part of Section IV I will discuss two studies based on regression models: (1) study of regional growth rates in West Germany between 1992 and 2002 (Mueller 2006); and, (2) study of industrially relevant science at universities of the OECD countries (Tijssen 2006).

Regression studies may be not directly contributing to development of the Triple Helix indicator. However, they may help to reveal some important characteristics of Triple Helix relations as well as suggest ideas concerning variables that should be taken into the consideration and their operationalization through available data.

Both Mueller (2006) and Tijssen (2006) are looking at modern developments at universities as they are transforming to more entrepreneurial mode and starting to perform the third function of contribution to the society. In this way, they are employing neo-institutional perspective on the Triple Helix model. However, they are looking at these developments from different angles.

Mueller (2006) uses regression model with regional economic performance (measured as regional gross value added) acting as a dependent variable. She uses the data on the economic development of Western German regions between 1992 and 2002. Not stopping deep on the methodology of the study, it is nevertheless useful to discuss some of the independent variables in the model, which may be important for the development of the Triple Helix indicator.

To begin with, R&D in private industries (RDI) and in universities (RDU) are used. However, operationalization the measurement of these indicators is not common: instead of R&D expenditures, Mueller (2006) uses share of employees in the private sector, which main activities are concentrated on R&D, for RDI, and share of researchers at universities in the total number of employees in the region, for RDU. Such operationalization may be not very good: number of researchers is not really measuring the real innovative output of universities (e.g., researchers in social sciences are hardly developing any product innovations). Besides, even those employees, who are working in the R&D departments of private companies, are not necessarily involved into R&D activities – they may perform managerial and/or coordinating functions. This means that using such indicator would overestimate the real level of R&D in private firms and universities.

One more variable, which is important for this study, is university-industry relation. It is measured by average amount of industrial grants per researcher. This indicator may be useful, however, it is not reflecting the whole variety of university-industry relations. First of all, industrial grants are actually showing only one direction of such relations: from industry to university. Besides, this variable is not taking into consideration the other types of university-industry relations rather than industrial financing of research. Therefore, this indicator would underestimate a value of university-industry relations.

As it was expected, all three variables added positively (and significantly) to economic development of regions, though effect of university-industry relations was rather small, when compared with RDI and RDU.

The model, developed by Mueller (2006), except for above stated problems with variables' operationalization is not taking into the consideration the other types of Triple Helix relations – bilateral interaction with government as well as trilateral relations. And though, Mueller concentrated on the entrepreneurial university as the centre of the model, considering the other Triple Helix relations would enrich the model.

The final study to be discussed in this paper is the study of industrially relevant science in 22 OECD countries (Tijssen 2006). The study is actually performed in two steps: on the first one, two indicators are suggested for measuring university-industry relations; on the second step these indicators along with some others are used as explanatory variables in the regression model with patent output of universities being the dependent variable.

Tijssen (2006) suggests two indicators which are supposed to measure industrially oriented science at universities and university-industry relations, namely: *University-Industry Research Cooperation Intensity (RCI)*[27] and *Industry-to-University Corporate Citations Intensity (CCI)*[28]. On the one hand, these indicators are again not reflecting the whole complexity of university-industry relations. The focus in these indicators is made only on the research activities within universities and private firms. Therefore, RCI and CCI would underestimate the relations between university and industry in the further research. As Tijssen (2006, p. 1575) shows, there is significant positive correlation between RCI and CCI ($r_{(CCI;RCI)}$=0,412). However, these indicators are determined by different factors: while RCI is mostly dependent on the R&D intensity of higher education sector, CCI is mostly influenced by the quality of domestic science base in both universities and private companies (measured as the standing in the international science citation index).

[27] "<...> the quantity of public–private co-authored research publications relative to total output of research publications produced by a university within the same time-interval" (Tijssen 2006, p. 1574).

[28] "<...> the quantity of references ('citations') within corporate research papers to a university's research output relative to the university's total output of 'citable' publications" (Tijssen 2006, p. 1574).

On the second step, Tijssen (2006) develops the regression model with patents being the dependent variable reflecting the entrepreneurial nature of a university. I have already discussed the pros and cons of patents as an innovation activity indicator in Section IV.5., so I am not going to do that again here. It is worth mentioning, that Tijssen (2006) considers only those fields of science and industries, to which patents are really reflecting the level of technological development: immunology research and neuroscience.

As for the independent variables, besides RCI and CCI, some statistics on the number of publications of different universities is used (total number of publications, publications in the immunology and neuroscience, public-private cooperative publications in immunology and neuroscience, etc.). Most of the variables as expected have positive influence on the patent output (easy to expect that the higher is the number of publications – the higher is the number of patents). However, RCI has negative influence on the patenting activities. This could be explained by two reasons. First one is more statistical in nature: not correct specialization of RCI (it is not measuring what is supposed to be measured). The other one is semantic: university-industry relations and patenting are interchangeable activities - university either concentrates on patent development (and, therefore, own entrepreneurial activities) or goes for relations with industrial partners. This conclusion may be extremely important for our understanding of university-industry and, in general, Triple Helix relations.

The limitation of Tijssen's (2006) study is the same as for the previous two – it ignores the other Triple Helix relations rather than relations of university with industry. However, it adds to understanding of the latter type of relations.

# V. DISCUSSION AND CONCLUSION

### *V.1. Summary*

In this paper, I tried to summarize and appraise the latest trends in Triple Helix empirical research in the stream of developing a quantitative indicator. It could be told without any doubt that empirical studies have helped, to some extent, to overcome weaknesses, for which the model was criticized. They helped to look at a micro-level of Triple Helix relations (Villanueva, Molas-Gallart and Esteve 2006), shed some light on university-industry relations (Meyer, Siniläinen, and Utech 2003; Mueller 2006; Tijssen 2006), and in general confirmed the main ideas of the Triple Helix model giving it more formal and less abstract nature. The main features of considered quantitative studies are summarized in a table in Appendix 1.

It should be mentioned here that only three approaches, namely mutual information, φ-coefficients/partial correlation and graphical analysis using the Vector Space model, can be strictly named Triple Helix indicators since they consider individual dynamics of helices as well as bilateral and trilateral relations among them. As for the other approaches, they are mostly concentrated on the concept of entrepreneurial university and, therefore, university as a primary institutional actor, while not considering the whole variety of Triple Helix relations. However, such studies have also contributed to understanding of the Triple Helix model and methods of measurement in its theoretical framework.

Even the brief look at features of empirical Triple Helix studies (see Appendix 1) shows that there is no unified approach towards measuring individual helices contribution to dynamics of national innovation system as well as bilateral and trilateral relations between institutional sectors (university, industry and government) or functions (wealth creation, knowledge exploration and normative control). Studies, considered in this paper, are different in terms of:

- *level of aggregation* – national/regional level or the level of individual researcher/research institution;
- *suggested systems of variables* – university-industry-government, geography-territory-organization, research output-networking features, etc.;
- *approaches of data collection and analysis* – scientometric data/bibliographic analysis, web-data/webometric analysis, regional economic performance/regression analysis, etc.;
- *considered relations between university, industry and government* – bilateral/trilateral/ quadrilateral relations;
- *perspectives on the Triple Helix model* – neo-institutional or neo-evolutionary.

In the other words, it is impossible to distinguish any single direction in which quantitative Triple Helix studies were performed and may proceed in the nearest future. However, having considered to-date-performed studies, I will try to propose some possible development paths and future research questions, which may be important for developing quantitative indicators for the Triple Helix model.

### *V.2. Research Agenda for the Future*

At least three prospective research areas may be identified on the basis of the study, underlying this paper.

First of all, complex dynamic nature of the Triple Helix model implies developing not one single indicator, but rather a system of indicators, which would cover different levels of aggregation. What is suitable for analyzing and comparing national/regional knowledge bases may be not suitable for explaining developments in different institutional actors (individual helices) within national/regional innovation system. The basis for such system development may be, for example, combining mutual information approach on the highest level of aggregation with embeddedness or patenting indicators at the level of individual universities, industries and government. Both indicators are based on similar type of data (data on publications/patents), which creates opportunities for developing the system of *interdependent* indicators.

The second area of future research should be studying university-government and industry-government relations using the theoretical framework of the Triple Helix model. As it was shown in Section IV, the biggest emphasis in quantitative studies is made on explaining university-industry relations, which is understandable, since major amount of knowledge produced by universities is being commercialized by industry. However, studying university-government and industry-government bilateral relations may (1) suggest some new ways of measuring bilateral relations in general; and, (2) shed some light on relations between university and industry as well (since government acts as a selection mechanism for university-industry relations).

The third direction of future research is, to some extent, connected with the second one. Some priority in the research should be given to finding better proxies for bilateral and trilateral relations between the helices. As, for example, I have shown in Section IV, operationalization of university-industry interaction variable through available data was limited, in most cases, to one single type of relationships, hiding, therefore, the whole complexity of bilateral relations. I would suggest that variables representing bilateral and trilateral relations should be not one-dimensional, but rather vector variables[29] comprising several factors reflecting multidimensional nature of such relations.

### *V.3. Policy Implications*

Suggested development of a system of indicators is also important from the point of policies and programs formulation. Different level of policies would require different indicators. For example, using mutual information indicator (with Storper's 'holy trinity' as individual helices) may be helpful when designing policies aimed at convergence between different regions within the country. Decomposing mutual information at a regional level before and after policy implementation would help to assess the efficiency of a policy and achievement of policy goals.

On the other hand, when planning a lower level policy of university research support through grants to university or individual researchers, it may be useful to consider patenting indicators (to define potential leaders of academic entrepreneurship) and embeddedness indicators (to define researchers with potentially higher research output).

This study may be, in this way, useful for policymakers since it presents different approaches towards measurement of Triple Helix relations, all of which may be used as indicators of policy efficiency, depending on its goals.

### *V.3. Limitations of the Study*

Two limitations of the study have already been considered in the methodology section of this paper, namely, over-presence of the studies performed by Leydesdorff alone or in collaboration with another researchers and consideration of only quantitative empirical studies.

One more important limitation should be mentioned. Except for the mutual information indicator, most of the other methodologies have been tested in only one case study. Therefore, I had to fully rely on the procedures and results presented by the authors of these studies. In order to confirm the reliability and generalizability of these approaches to quantitative Triple Helix analysis, it is necessary to apply them to another countries/regions/research institutions. This may be one more possible direction for the future research.

[29] For example, bilateral relations between university and industry should not be the function of one argument: $UI=UI(x_1)$, but a function of several factors: $UI=UI(x_1;x_2;\dots;x_n)$.

### *V.4. Concluding Remarks*

One can confidently assert that during the latest 15 years a huge step was made from developing foundations of the Triple Helix concept to performing empirical studies in its theoretical framework. It is now possible to measure the Triple Helix relations and their effect on a national innovation system. However, it is still necessary to continue research on the Triple Helix indicators and, in general, mathematical formalization of the model. I hope that by reviewing and appraising quantitative studies in the stream of the Triple Helix model and by clarifying their underlying theoretical assumptions and key methodological issues, I could bring a contribution to the future empirical and conceptual Triple Helix research.

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## APPENDIX 1. SUMMARY OF THE QUANTITATIVE STUDIES ANALYSIS

| Indicators | Mutual Information of University, Industry, Government (and international co-authorship) | Mutual Information of Geography, Technology and Organization | φ-coefficients and partial correlation |
|---|---|---|---|
| **Theoretical Foundations** | Triple Helix model; mathematical theory of communication; Shannon's theory of information | Triple Helix model; mathematical theory of communication; Shannon's theory of information; Storper's 'holy trinity' | Triple Helix model; correlation analysis |
| **Methodology** | Bibliographic analysis; scientometrics | Quantitative analysis of the data | Bibliographic analysis; scientometrics |
| **Data** | Publications in the Science Citation Index | Data on firms in the national register of companies | Publications in the Science Citation Index |
| **Dependent Variable/ Indicator** | Mutual Information measuring the systemness of the economy | Mutual Information measuring the systemness of the economy | φ-coefficients and partial correlation measuring the bilateral and trilateral relations between institutional actors |
| **Independent Variables (if any)** | Contributions from single institutional sectors, their bilateral, trilateral (and, quadrilateral) relations | Contributions from single elements of Storper's 'holy trinity', their bilateral and trilateral relations | Contributions from single institutional sectors, their bilateral, trilateral (and, quadrilateral) relations |
| **Relations of Institutional Spheres (or Dynamics) under Consideration** | Internal dynamics of each Triple Helix component (University, Industry, and Government), pairwise interaction dynamics (UI, UG, and IG), Triple Helix interactions (UIG).<br>Plus, foreign co-authorship relations (Leydesdorff & Sun 2009). | Internal dynamics of Geography, Technology and Organization, pairwise interaction dynamics (GT, TO, and GO), trilateral interactions (GTO) or all of them | Pairwise interaction dynamics (UI, UG, and IG), and to some extent Triple Helix interactions (UIG). |
| **Perspective on the Model used for the Study** | Combination of neo-institutional and neo-evolutionary perspectives | Neo-evolutionary perspective | Combination of neo-institutional and neo-evolutionary perspectives |

## APPENDIX 1 (CONTINUED). SUMMARY OF THE QUANTITATIVE STUDIES ANALYSIS

| Indicators | Contribution from the Vector Space model | Contribution from the Embeddedness theory | Patent based Triple Helix indicators |
|---|---|---|---|
| **Theoretical Foundations** | Triple Helix Model; Vector Space model | Triple Helix Model; embeddedness theory; entrepreneurial university concept | Triple Helix Model; entrepreneurial university concept |
| **Methodology** | Webometrics | Statistical analysis | Statistical analysis |
| **Data** | Data on the outlinks from the web-pages of research institutions | Questionnaires filled by university researchers | Data on the patents from the US Patent and Trademark Office |
| **Dependent Variable/ Indicator** | Positioning in the system of standard vectors of university, industry and government | Research output of a single researcher | Total Inventive Activity of the Universities; Concentration of Patents; Share of Patents Utilized in Start-Up Companies and Share of Patents Utilized in Large Companies and Established SMEs; Share of Unassigned and Foreign-Assigned Patents |
| **Independent Variables (if any)** | Vectors of single research centres | Degree of embeddedness; nodal heterogeneity | --- |
| **Relations of Institutional Spheres (or Dynamics) under Consideration** | Triple Helix interactions (UIG) | Interaction of university with academic and non-academic institutions. | Interaction of university with industrial institutions |
| **Perspective on the Model used for the Study** | Neo-institutional perspetive | Neo-institutional perspetive | Neo-institutional perspetive |

## APPENDIX 1 (CONTINUED). SUMMARY OF THE QUANTITATIVE STUDIES ANALYSIS

| Indicators | Regression model on the regional economic performance | Regression model on the patenting activity of universities |
|---|---|---|
| **Theoretical Foundations** | Triple Helix Model; Entrepreneurial university concept; Endogenous growth theories | Triple Helix Model; Entrepreneurial university concept |
| **Methodology** | Statistical and regression analysis | Statistical and regression analysis; Bibliometric analysis; Scientometrics |
| **Data** | Data on the regional economic performance | Data on the number of patents issued to a university; data on publications from the Science Citation Index |
| **Dependent Variable/ Indicator** | Regional GDP | Number of patents granted to university |
| **Independent Variables (if any)** | R&D in private industries and in universities; average amount of industrial grants per researcher | University-Industry Research Cooperation Intensity; Industry-to-University Corporate Citations Intensity; number of publications of a university |
| **Relations of Institutional Spheres (or Dynamics) under Consideration** | Interaction of university with industrial institutions | Interaction of university with industrial institutions |
| **Perspective on the Model used for the Study** | Neo-institutional perspetive | Neo-institutional perspetive |