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PUBLIC, PRIVATE AND ACADEMIC SECTOR INTERACTION FOR HIGH TECHNOLOGY DEVELOPMENT

Neringa Petrauskaitė[1], Eugenijus Chlivickas[2]

Vilnius Gediminas Technical University, Faculty of Business Management,
Saulėtekio ave. 11, LT-10223 Vilnius, Lithuania
Email: [1]neringa.petrauskaite@vgtu.lt; [2] eugenijus.chlivickas@vgtu.lt

Abstract. Successful development of high technologies due to its specifics and complexity of the problem to be solved is pursued on the basis of 'triple helix' model. Scientific researched has proved that the same development model may work differently in each country or region since 'triple helix' effectiveness immediately depends on system elements and the interaction complexion and intensity of participating elements. Thus, the article aims to identify the key factors affecting high technology development through functioning of the system including public, private and academic sector interaction. For that purpose a scientific approaches has been studied. Finally, the results of the analysis have been verified by science-based methods.

Keywords: innovation, high technologies, 'triple helix', public sector, private sector, academic sector.

Jel classification: O32

1. Introduction

Studies of scientists as well as strategically significant documents of national and international organizations tend to focus on the importance of high technologies in the period of intensive economic globalization because high technologies development is a strategically essential area promoting efficiency of a regional and national economy and ensuring a competitive edge of a region and a country. That is why a number of publications are devoted to analysis of state-of-the-art high technology development systems and of factors affecting high technology development. There is a consensus in scientific literature that high technology development primarily depends on the high technology development model applied as well as on the way this model is functioning. Therefore, high technology development is dependent on the functioning of the model that serves as the basis for factors which determine high technology development.

Thus, the goal in the present paper is to identify the key factors, affecting development of high technologies. For this reason detailed analysis of different approaches devoted to state-of-the-art high technology development models was carried out and expert assessment must was conducted to evaluate the importance of the key factors for high technology development. Thus the subject of the research is the factors of high technology development.

2. 'Triple helix' for high technology development

Development of high technologies requires a complex approach. In the 1980s, the United States saw the introduction of a new model by Etzkowitz and Leydesdorff intended to promote the development of the high technology sector. A 'triple helix' phenomenon was used to express the principles of the model, which previously had been in wide use in other fields of science, such as crystallography, molecular biology, etc. The structure of the model gave it the name of the 'triple helix' model.

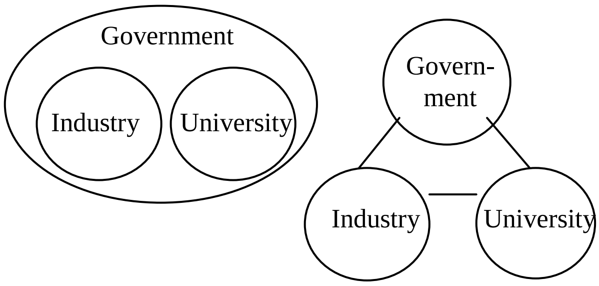
The model was advertised as a useful method in promoting entrepreneurship and economic growth (Brundin *et al.* 2007) as well as innovation (Etzkowitz, Dzisah 2007) at national or international level (Freeman 1995; Etzkowitz, Leydesdorf 2000).

The 'triple helix' model gives an integrated and detailed picture of the innovation process as a recursive interaction system that stresses the importance of knowledge-based economy. The 'triple helix' model indicates a relationship among the university (Dzisah, Etzkowitz 2008; Etzkowitz, Carvalho de Mello 2004; Leydesdorff 2006) or generaly named by other authors as academic public (Etzkowitz 2002; Brundin *et al.* 2007), industry and authorities as an entirety of overlapping areas reflecting an impact of each element to other spheres.

Etzkowitz, Gulbrandsen and Levitt (2000) and Wessner (1999) analysing development of high technologies in different regions of the world distinguished three main configurations of the 'triple helix' model.

The first model (Fig. 1. a) reflects a situation, which in the opinion of the authors is characteristic of the former republics of the Soviet Union and some Latin American countries. The areas indicating elements of the industry and academic public exist independently without interacting. The dominant role of an intermediary is played by the authorities being the only element ensuring relations among the sectors. This model represents situation in which the state incorporates industry and academic public, where state owned industries are predominant.

The second model (Fig. 1. b) shows mutual relations of different elements but does not reflect their advantages and influence to generation of new ideas, creation of innovations and development of high technologies. In the opinion of the authors this model is characteristic of the United States of America. The model allows to establish relations between different spheres, when each of them plays an independent role in the own area only, but does not express the nature of those relations.



a) b)

Fig.1. The 'triple helix' model with a) one dominating element b) mutual relations (Source: Etzkowitz *et al.* 2000)

The continental Europe and countries referred to fastest economic growth showing countries typically have the 'triple helix' model the elements of which closely cooperate without distinguishing importance of any sphere.

Researchers Viale and Campodall' Orto (Viale, Orto 2002) attribute the latter model to the USA, EU and other countries with a close cooperation among separate institutions of science, business and government.

The application of different configuration of the 'triple helix' model depends not only on determined goals in science and area of research and development, but also on political and socio-economical situation in the country. The first model in which one sphere dominates the others is suitable for the countries with strong influence of authorities, where the government sets the priorities in industry development and provides financial tools for it. The tendency is observed in the countries with close type of economy, with strong ideological dominance in socio-economy or during the economical transition from one form to another. The second model of institutional spheres as separate from each other is applied in countries with numerous population and difficult system of institution, such as federation, confederation or commonwealth. This model allows to manage investments and to allocate them properly into different spheres of industry and academia. Element of authorities plays the role of meeting point for state, industry and academia interests.

The third model with overlapping spheres (Fig. 2) shows the highest grad of cooperation between elements. This way of cooperation may be found in practice in countries with stabile economical and political environment, foreign trade liberalization and business internationalization. The last configuration of 'triple helix' model allows solve all problems in innovations implementation in form of negotiation and transaction.

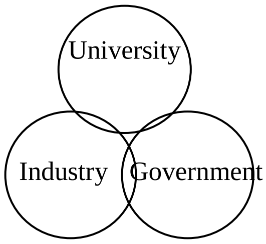


Fig.2. The 'triple helix' model of overlapping elements (Source: Etzkowitz *et al.* 2000)

With a view to promoting high technology development on the basis of this model, it is especially important for each element of the system to perform its role and task in due manner and interact with the other elements. According to the 'triple helix' theory, stakeholders involved in the process of knowledge generation gradually take over part of the roles of the other stakeholders (Brouwers *et al.* 2009; Brundin *et al.* 2007; Etzkowitz 2003; 2007; 2008), thereby providing conditions for dynamic interaction and intermingling of interests and views. For these reasons, all elements of the system undergo changes in order to achieve their aims for the sake of the common mission, by performing the traditional and new functions.

2.1. Public sector in high technology development

The policy that the state performs in the system of the most advanced innovation development models is that of support based on coordination, control and promotion. As a result, the government is one of the key elements of the 'triple helix' model, whose absence would undermine the effective interaction of the other two elements, in particular the academic community and industry. Its role in the innovation and high technology development in different countries has been analysed from different aspects by a number of scholars.

Summarising the scientific different approaches, it can be maintained that, first of all, according to Leydesdorff (2006), the government can be viewed as a variable of this model that institutionalises and organises the systems in the geographical dimension of the model. In other words, it is a source of contractual relationships that ensures constant interaction and exchange (Etzkowitz, Carvalho De Mello 2004) and attracts the other two spheres to attain regional innovation (Etzkowitz *et al*. 2007). Thus, the main task of the government in the 'triple helix' is **policymaking**, as well as control and monitoring of high technology development, so the government is responsible for creating and implementing a high technology development monitoring system.

Depending on government policies, universities may create joint ventures with private undertakings (Eun *et al*. 2006), or companies may hire graduate students to conduct R&D projects (Tödtling *et al*. 2009), or create an environment that attracts new technology-bases start-up companies (Etzkowitz *et al*. 2005).

To implement its goals, states use the most different policy instruments. The majority of the authors of scientific literature stress the particular importance of **financial instruments for high technology development**.

In forming a favourable environment for high technology businesses, the public sector creates and implements different programmes designed to fund research (Etzkowitz 2001), develops a favourable tax environment and appropriates financial capital (Etzkowitz *et al*. 2007; Etzkowitz, Dzisah 2007). The government assigns direct support for applied and fundamental research, for establishing laboratories or creating research systems, research parks and training centres, mostly by founding innovation clusters. The government also contributes to high technology development through investment in shares or, according to Holbrook and Salazar (2004), "by **conducting independent research and experimental development at public institutions**".

Other possible direct high technology policy implementation measures include information (i.e. advice) and brokerage support, schemes for raising awareness about high technology, support for networking, i.e. support for clubs exchanging information and for activities such as foresight programmes, which aim to develop common vision around which future oriented R&D networks can be formed, and co-location measures (e.g. R&D parks).

Moreover government takes on a much more entrepreneurial orientation: it does not just try to create a general political economic climate favourable to business investment but, also **actively intervenes at all points in the product development cycle**: basic research, applied research, product development, and marketing (Fosler 1988).

2.2. University in high technology development

The key functions of the traditional academic community that mostly features as universities in the 'triple helix' model are **training and knowledge production.** The result of implementation of the first function, i.e. training, is reflected by the number of graduates (bachelors, masters and doctors), while the result of knowledge production can be measured by the number of scientific publications and patents.

Universities are inseparable from the process of creating innovation and high technology products. This is because universities are the main source of knowledge necessary for research, as well as a source of specialised knowledge which is available for firms to draw upon in their applied technology activities, in addition to their responsibility for training scientists and engineers capable of solving problems in firms related to innovation processes, and for training students in general who represent an enduring source of innovation at the university and in their movement to other institutions of the 'triple helix' system after graduation (Etzkowitz 2007).

A new function of the academic community in the 'triple helix' is **knowledge transfer to industry**, i.e. commercialisation of knowledge. The emergence of this function was also determined by the second academic revolution at end of the 19th century and the beginning of the 20th century, raising a new mission for the academic community, with research and economic and social development becoming a new mission (Dzisah, Etzkowitz 2008). The 'triple helix' model developed within the context of this concept has complemented the traditional higher education system with "a culture of entrepreneurship, innovation and technology transfer" (Etzkowitz, Dzisah 2007), while universities, continuing their significant mission of socialising young people and disseminating knowledge, have begun to take over some the functions from industry and the government (Etzkowitz 2007). In scientific literature this transformation is defined as a transformation of universities to entrepreneurial universities. Entrepreneurial universities extend their mission in higher education and academic research to assume the role of stimulating economic innovation in the environment (Leydesdorff, Meyer 2007). As the industry sector absorbs this knowledge, new ideas and a need for scientific knowledge are born, which promotes further collaboration.

The main purpose of university-industry collaboration in the 'triple helix' system for high technology development is to "complement companies' resources by producing high qualified scientific knowledge" (Zawislak, Dalmarco 2011). This purpose of collaboration has determined the emergence of new forms of interaction institutes and of knowledge sharing between universities and industry, including the establishment of technology-based spin-offs in the university environment, such as business incubators, science and technology parks, etc.

The university is also responsible for **forming new firms in incubator facilities**. According to Marques et al. (2006), as a result of all their functions, in the 'triple helix' system universities have become a key player as both suppliers of human capital and as the physical space for innovation development.

2.3. Industry in high technology development

Industry first of all is responsible for economic production and trade. Main goal of industry in high technology sector within the 'triple helix' for high technology development is to **absorb knowledge** for improvement of technological productivity. Technological productivity is associated with the science-intensity of patents (Leydesdorff, Meyer 2007). A firm can enhance its absorptive capacity by training its personnel, by carrying out R&D, and by using advanced manufacturing equipment (Schiller, Diez 2007).

Two different kinds of high technology companies are identified according to the source that has generated knowledge used by industry to develop high technology products and the methods of its use (Batisa de Sousa 2011): market orientated – apply research to improve products, and research orientated – that search a market for their research reslults. In the former case, it is evident that the industry sector also contributes to high technology development by independent **research**, which represents a new function of industry in the 'triple helix'. Industry takes role of the university in developing training and research, often at the same high level as universities (Etzkowitz *et al.* 2007), and industrial labs made the transition from supporting existing production processes to creating new products utilizing the methodologies of basic science. It can be sad, that as noted by Brundin *et al.* (2007), industry develops an academic dimension in their daily work. Research results are used for new product development, while training helps to conduct research successfully and to absorb knowledge generated by different sources.

Another most common function of industry encountered in scientific literature is **financing of high technology development**.

Normally R&D is financed with funds of the business sector, the public sector and the higher education sector. Such financing often uses foreign funds as well. However, the greater part of the funds usually comes from the business sector or the public sector. According to Eurostat data of 2009, in less than half of the EU member states more than 50 per cent of the funds for R&D were from one source. Such sources usually included private sector.

2.4. Importance of interaction of 'triple helix' elements for high technology development

The success of the model mostly depends on the collaboration among the elements in the 'triple helix'. As found by Konde (2004), in many countries the triple helix entities seem to be weak because their elements tend to work in isolation. Therefore there exist 'triple helix' models of overlapping elements with negative and positive overlap among the three subsystems.

In first case system operates over time in terms of different communications at the respective interfaces (e.g. university-industry; university-government etc.) and as explained by Leydesdorff (forthcoming) the three systems are integrated in distributed mode therefore integration remains symbolic. Under the condition of a lack of overlap among the three sets, the mutual information in three dimensions is negative (Abramson 1963).

In the second case the overlap is positive. Overlap appears in various shapes under interaction of elements of the system. For example, **government and academic linkages** include various grant programs, as well as forums and means of information exchange, while **government and industry linkages** include industry liaison and lobby groups that represent large numbers of clients in an industry, as well as government programs to lever the collective nature of business (Vogel 2005).

University and industry linkages are most probably the most important within the 'triple helix'. The interorganisational relationships and partnership has significantly increased in recent years (Plewa, Quester 2006).

University and industry interaction for high technology development can be differentiated into two groups: **financial cooperation** and **cooperation when transferring knowledge**. Therefore it is possible to measure university-industry collaboration first of all by the amount of funds spent for university-industry joint projects or donated by the industry to universities. Transfer of knowledge can also be evaluated after assessment of a number of knowledge transfer indicators that can be grouped into ten groups.

First of all, it is knowledge transferred through the *establishment of new firms* (1), i.e. spin-offs or technology start-ups. The knowledge also can be trasfered through *intermediate organizations* (2) both internal to the university and external. Internal intermediaries include science and technology parks, incubators while external intermediaries include venture capital firms, business angels, surrogate entrepreneurs and development agencies.

Knowledge can also be transferred by means of *licensing* (3), which means the granting of permission or rights by one party entitled to licensing to another party to use and sell a certain work (product, design, etc.) or *during meetings* of various stakeholders *or when scientific works and patents are made available using other forms* (4). This includes meetings of scientists and other stakeholders, conferences, working groups and seminars, courses and training, lectures and training at universities conducted by employees of corporations and technology demonstration, e.g. by creating prototypes and making scientific publications, inventions and patents available otherwise.

Knowledge sharing also occurs through *employee movement* (5), or, as Hatakenaka (2009) has called it, brain circulation. Such movement is enabled by exchange programmes or by simply recruiting professionals for paid employment and consulting, or by employing university graduated in companies.

The main purpose of *alliances* (6) is the same – knowledge transfer. Alliances, include strategic alliances, other knowledge transfer also networks (Howlett 2010) or, in other words, hybrid institutions that interact also for non-profit purposes (Marques *et al.* 2006). *Informal social relationships* (7) also play an important role in knowledge sharing.

Knowledge is also shared in other forms of collaboration, such as *joint academic activities* (8), e.g. joint leadership of doctoral thesis and graduation papers or preparation of joint publications, as well as *joint R&D activities* (9), including joint R&D projects, jointly applying patents (by university members and company researchers) also while consulting each other; or *sharing infrastructure* (10), e.g. lease or non-refundable sharing of laboratory and equipment.

3. Key factors determining high technology development potential and their expert assessment

Analysing the principles of functioning of the state-of-the-art 'triple helix' model, it can be stated that the key groups of factors that affect high technology development are as follows (Table 1):

Table 1. Key factor, affecting high technology development

	Key factors	Explanation
Conditions	Environmental conditions	They include political, legal, economical, technological and social environment where high technology is developed.
Resources	Human resources	It includes scientists and engineers that produce knowledge.
	Financial resources	It include direct and indirect financing from all financing resources.
	Knowledge	It includes available knowledge that can be transferred and commercialised.
Processes	Knowledge transfer	It includes various technologic and managerial knowledge transfer shapes in 'triple helix' system that are necessary to commercialise produced knowledge.

In order to determine the significance of the individual elements of the 'triple helix' referred to in scientific literature and of their interaction for high technology development, expert assessment is carried out. Expert assessment is understood as a consolidated opinion of a group of experts, obtained by using expert knowledge, experience and intuition.

In this case, the purpose of expert assessment is to carry out an evaluation of identified groups of factors, by determining the weightings of those factor groups, and later to verifying the consistency of expert opinions.

After identifying groups of the key factors expert assessment phase follows. In this phase, the two aspects that have special importance in determining the weightings of indicators are the selection of experts (their number and competence) and the rating scale.

In order to determine the significance of the ‘triple helix’ elements and of their interaction for high technology development by way of an expert survey, a group of specialists in the high technology sector (scientists and top-level management of high technology companies) is formed. Scientists have proved that in aggregate expert assessment modules with identical weightings the accuracy of assessment by a small group of experts is equivalent to the accuracy of assessment carried out by a large expert group. In the opinion of most scientists, the optimum size for a group is from 8 to 10 experts. In the present case, the survey involved eight experts. Thus, based on the calculations by Augustinaitis *et al.* (2009) and Brock, Hommes (1997), the reliability of such assessment is about 90 per cent. Later expert assessment follows.

Using expert assessment for determining the weightings of the criteria, it is necessary to provide methods for experts to express their assessment. There are different methods for decision makers to express their assessment by using scales of different sizes, as well as rankings, scores, percentage rates, etc. In the present case, the decision maker is provided with a group of criteria that have an effect on high technology development, and the decision maker expresses his individual assessment on a six-point scale (where 1 means not important and 6 – very much important) that a computer programme converts into the weightings of the criteria. The weightings of the criteria are assessed within this scale and normalised in the interval [0, 1], which is the most widely used scale of the weightings of criteria (Bivainis, Butkevičius 2003; Podvezko 2005). Thus, the sum of the weightings of criteria equals 1.

The assessment of the eight experts in the high technology field is shown in Table 2. The calculations reflect the average assessment of the indicators and their weightings ωi.

Table 2. Factor ranking with expert assessment method

Key factors	Experts								Dispersion coefficient of concordance	Rank avarage	Weight of indicators
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**			
1	4	3	4	4	3	5	2	3	28	3,5	0.114
2	7	7	7	7	7	7	6	7	55	6,88	0.224
3	6	7	7	5	6	7	7	7	52	6,5	0.212
4	7	7	7	7	7	7	7	7	56	7	0.229
5	6	6	7	7	7	7	7	7	54	6,75	0.220
Total									245	30,63	1

For determining the concordance (consistency) of expert opinions, the coefficient of concordance *W* is used to define the level of consistency. Calculating the coefficient of concordance requires a preliminary ranking of the indicators with respect to each expert (Podvezko 2006).

The coefficient of concordance is calculated according to a formula that characterises the level of coincidence of individual opinions (Zavadskas *et al.* 2001) (1):

$$W = \frac{125}{r^2(m^3 - r\sum_{j=1}^{r} T_j)} \quad (1)$$

where: *r* – the number of experts; *m* – the number of factors; *S* – the sum of squared deviations of rank totals from the average rank total; *Tj* – correction factor for tied ranks.

To calculate the coefficient of concordance, data necessary for such calculation were computed.

The table shows that total average of the rankings equals 49, and the sum of the squares of the deviations of the indicator ranking sums from their total average is *S*=560.

Using these values in the formula, the resulting value of the coefficient of concordance is *W*= 0.875 (when *S* = 560; *r* = 8, *m* = 5).

The statistical level of expert consistency is expressed by the criterion X^2 calculated according to the following formula (2):

$$X^2 = \frac{125}{rm(m+1) - \frac{1}{m-1}\sum_{j=1}^{r} T_j} \quad (2)$$

where the statistical value of X^2 is higher than the critical X^2_{cr} (from the X^2 distribution table where *v* = *m* – 1 degree of freedom and the selected weighting level *α*), this means that assessments by experts are consistent and the indicator weightings can be applied to quantitative multi criteria assessment (Podvezko 2005). In practice, the value of α usually is 0.05 or 0.01.

Calculated in accordance with the latter formula, the value X^2 = 28 exceeds the critical X^2_{cr} = 9.49 with the weighting level α = 0.05 and *f* = *m* – 1 = 4 degree of freedom. This shows that the expert opinions are consistent.

4. Conclusions

Developing high technology requires a systemic approach to this process. At present, the most advanced model for high technology development is the ‘triple helix’ model with overlapping system elements that institutionally involve universities, the government and industry. High technology development is dependent on the functioning of this system, i.e. on the functions performed by each element and on the elements' interaction.

The crucial aspect of the 'triple helix' is that each system element, in addition to its traditional functions, also takes over the functions from the other elements. In this case, the government shapes high technology development policy that provides favourable economic, social, legal and other conditions for high technology development, as well as through R&D financing and independent R&D projects, i.e. by generating knowledge, although knowledge generation is the key function of universities in this system. Universities are also responsible developing full of potential human capital necessary for technological knowledge production, while the input of industry to high technology development is R&D financing and knowledge production, absorption and commercialisation. However, the factor crucial for the effective functioning of the system is knowledge sharing that can take various forms.

Summarising the different approaches studied and taking account of the defined guidelines, five key factors affecting high technology development have been identified, including environmental conditions, human and financial resources, knowledge and knowledge transfer. Using expert assessment method it was found that high technology development mostly depends on knowledge and potencial of human resources.

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