The Evolution of Innovation Networks in Slovakia: Disintegration and Slow Recovery

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Abstract Knowledge production processes during the transition period from authoritarian socialism to market economy experienced significant changes in Slovakia and other CEE countries. Such a paradigm shift has caused the disintegration of the former inventory networks followed by only a slow recovery over the last 20 years. The patenting activity analysis of Slovak institutions gives a good focal point to indicate the general decrease in innovation performance and also to justify the breakdown and fragmentation of the former long-term cooperating inventory networks during the period of 1998–2012. The Slovak regional inventory networks have been studied for a longer period using network analysis, discovering common evolutionary development as well as particular network patterns after the opening of the economy to competition and foreign investments, staying before in a comfort zone. The recovery and formation of new networks of inventors are still very slow, even if the economic growth is steadily positive. One of the main reasons for continuing lower innovation performance is not only the low expenditure on research and development, but another reason is a relatively low number and quality of the links within poorly developed regional innovation systems. The results of the network analysis demonstrate to what degree the regional innovation system is truly regional (or national or even international) by comparing Slovakia's regions and their interdependencies.

1 Introduction

In the socialistic period, Central and Eastern European countries have advocated linear innovation approach to research and development with a limited horizontal cooperation (Koschatzky 2002), although their governments considered science and technology as an integral part of each industry (Graham 1990). Fritsch and Graf (2011)

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analysed how different history and macroeconomic conditions shaped regional innovation activities. Their findings for East and West Germany indicate significant structural differences between their innovation networks. Similar to East Germany, the Czechoslovak economy after the Second World War was characterised by the massive industrialisation. The government enforced machine engineering and chemical industry, and not surprisingly the most patent applications come from those two industries, especially in the years 1988–1992 (Smith 1998).

Transition to a market economy after November 1989 has brought to the Slovak economic area dramatic fragmentation and deindustrialization. The privatisation and dynamic industrial restructuring also affected the networks of innovators. The following part aims to explain the evolution of the inventory networks in the period 1988–2012 and to catch the impact of the economic transition in Slovakia.

2 The Socialistic Period of Slovakia

2.1 Transition and Institutions

After the Communist rule came to an end in 1989, the countries of Central and Eastern Europe had to cope with the transition from the centrally planned economy to market economy and from the ultimate state ownership to the private property. However, the economic transformation has not been the only critical change. Simultaneously with the economic system change, a less quantifiable transition from the centralist authoritarian rule to a pluralist democracy, as well as from party and state-dominated societal organisation to a civil society has taken place (Illner 2000). The transition from authoritarian socialist system to democracy and market economy in Poland, Czech and Slovak republics followed a shock therapy model (Morvay 2005), and was formally and institutionally completed by the entrance to EU in 2004. In comparison to a more radical approach in the Czech Republic, where a more sharp approach for the economic recovery was ongoing, Slovakia and Hungary adopted a more gradual and modest approach (Radosevic 1996).

The discussion on the transition from the former centrally planned economies to a market economy more or less ended at a macro level. Nevertheless, the past is still preserved in the formal and particularly informal institutions. In the former communist countries, there has been a clear change to standard market formal institutions. However, the change in informal institutions is not straightforward or is even in a clash with the new economic system. The present discrepancies between the functioning of the former CEE communist countries and Western Europe at the national, regional and local levels can be certainly explained by a number of factors—although probably the weightiest variable is the heritage of centrally planned economies.

In fact, Slovakia and some other CEE countries experienced two revolutionary changes in the second half of the twentieth century, which have broken up theoretically natural economic and societal development. The former one has changed the political and economic system from market to forced state ownership after the World War II. After 50 years of living in an entirely different institutional framework, the last utter change to market economy meant a deep-drawn switch to a new, unfamiliar system, taking wide-ranging and difficult transition the second time.

That is why the CEE countries in transition constitute a considerably challenging issue for evolutionary economic theory and path dependence concepts (Buček et al. 2013). An evolutionary approach should take into account two radical shocks, to sufficiently interpret their situation at the beginning of the twenty-first century. Informal rules of the central planning are still alive or have transformed themselves into new forms of paternalism, acceptance of privileges, tolerance to rent seeking, lobbying the government, favouring national and sectoral over regional and local, or directive management influencing relations between economic agents (Tridico 2006). The evolution of new institutions is affected by the persistent old rules and path dependence shapes the transformation.

2.2 Development of the Czechoslovak Economy in 1948–1989

Czechoslovakia was one of the most developed economies of the world during the interwar period. Already in 1930, 45% of the population was working in manufacturing and mining and only 30% in agriculture. The neighbouring countries showed a rather different picture that time in comparison to Czechoslovakia, with 67% of the active population working in agriculture in Poland and 54% in Hungary (Myant 1989). After February 1948, the nationalisation brought 95% of industrial employment within the state sector. Based on the general plan, a new economic structure has been developed, emphasising industrialisation and heavy industry especially. To a large extent, the building of new industrial structures and focus on industrial production in the COMECON countries (COMECON—the Council for Mutual Economic Assistance, an economic organisation led by the Soviet Union, existing 1949–1991) were being subordinated to the demands of the USSR. The foreign trade of Czechoslovakia grew quickly from 40% share of the COMECON countries in 1948 to 78% in 1953. The decisions on the location of new industries have been made centrally, aiming to provide the employment in all regions of the country, but without considering regional interests, with an orientation towards East European markets (Morvay 2013).

The massive industrialisation has brought ambiguous consequences to the Slovak economy. The share of the industrial production on the national income was 39.9% in 1948 and immediately reached 53.8% in 1953. However, the industrialisation progression resulted in establishing industries with only low value-added and a low degree of finalisation (Koyame-Marsh 2011). A more sophisticated industrial production in the Czech Republic sourcing from the interwar technical basis enabled the spread of technology and development also to the Slovak part of the country. For example, the Czech automobile car, truck and motorcycle production originated at the very beginning of the twentieth century and the main producers before the WWII were Škoda, Praga, Tatra, Aero and Jawa (Pavlínek 2008). In the period of 1955–1975, the decisions of the State Planning Commission enabled the establishment of branch plants also in Slovakia following the official regional development policy to industrialise the territory of Slovakia (BAZ in Bratislava, TAZ in Trnava and several other cities). As at 2016, Slovakia and the Czech Republic are countries with the highest production of cars per capita in the world. The German Volkswagen acquired the BAZ small production plant in 1991 and the French PSA (Peugeot and Citroën) built a new car assembly plant in 2006 in Trnava taking advantage of the existing qualified workforce. This example of automotive industry evolution explains the spread of the industrialisation from the Czech to the Slovak part of Czechoslovakia, as well as from more industrialised regions to less urban and peripheral areas. Later on, a highly uncompetitive production in many cases of the plants imbedded in less urbanised regions appeared, just after the breakdown of the Soviet bloc and following stagnation and decline of Eastern markets of the ex-COMECON countries.

In the second half of the twentieth century, structural dysfunctions of the centrally planned economy, the costly arm program implemented by the socialistic regime and oil shocks in the 1970s caused Czechoslovakia to lose its former innovativeness and competitiveness. The transformation process and opening of the economy and markets in the 1990s have revealed declining Czechoslovak economy, lagging of technical infrastructure, serious deficiencies, a hidden inflation and overestimated economic indicators (Morvay 2013).

Table 1 provides officially reported and collectable data of available macroeconomic indicators in the period of communistic government (1960–1989) in Czechoslovakia based on Historical Statistical Yearbooks of Czechoslovak Federative Republic[1] (ČSFR). As Table 1 shows, the national income and customer consumption have been increasing over the whole period of the socialistic economy of scarcity in Czechoslovakia. However, the official statistics does not include the hidden inflation and other dysfunctions in the economy, which have appeared fully only after the breakdown of the previous regime. The national income and customer consumption have been increasing significantly over the whole period of the socialistic era in Czechoslovakia 1948–1989. The picture of the economic development of the Czechoslovak economy would not be complete without comparing both their parts. First, there is an obvious huge difference in the structure of the economy of the Czech and Slovak parts of the country at the beginning of the socialist period. Slovakia started its massive industrialisation only in 50ties: the share of industrial production on GNI was 39.9% in comparison to 58.6% in the Czech Republic. At the end of the period in 1989, the share of industry settled at over 60% in both territories.

[1]Official names of common state in times of Czechoslovakia:
1918–1960: Czechoslovak Republic (excluding 1945–1948),
1945–1948: Protectorate of Bohemia and Moravia and Slovak Republic,
1960–1989: Czechoslovak Socialistic Republic,
1990–1992: Czechoslovak Federative Republic.

Table 1 Basic macroeconomic indicators of Czechoslovakia (1948–1989)

	1937	1948	1953	1960	1968	1970	1975	1979	1980	1982	1983	1984	1985	1986	1987	1988	1989
		Czechoslovakia		**The Czechoslovak Socialist Republic**													
		Period of Communist government															
National income (in mill. Kčs[a]—current prices)												541,101	556,325	570,048	583,257	606,380	619,405
Personal consumption (in mill. Kčs—current prices)												287,210	297,555	306,054	315,260	330,362	343,202
Share of personal consumption on national income												53.08	53.47	53.69	54.05	54.48	55.41
Growth of national income per inhabitant																	
1937 = 100 (%)	100	113	170	257	331	376	481	544	557	556	567	585	601	615	626	639	644
1948 = 100 (%)		100	150	227	293	332	425	481	492	491	501	517	531	543	553	565	569
Czech Republic																	
1948 = 100 (%)		100	153	245	326	364	468	523	532	528	534	548	562	576	587	600	616
Slovak Republic																	
1948 = 100 (%)		100	169	311	480	536	743	860	887	885	913	955	989	1038	1077	1114	1132
Share of industry in the generation of national income (current prices)		58.6	66.8	62.3	60.1	61.0	64.7	63.3	63.5	60.6	61.2	58.7	59.8	59.8	59.9	59.6	58.3
Czech Republic		63.1	70.3	65.9	64.0	65.4	68.4	67.2	66.9	65.4	65.0	64.1	64.8	65.3	65.7	65.7	62.3
Slovak Republic		39.9	53.8	51.7	54.5	56.9	62.4	63.0	64.2	61.8	63.2	62.8	64.1	63.6	64.1	64.0	61.7
Growth of personal consumption per inhabitant																	
1937 = 100 (%)	100	97	112	176	234	252	309	327	325	322	328	333	337	344	353	370	376
1948 = 100 (%)		100	115	181	241	260	319	337	335	331	337	342	348	353	364	381	387
Selected sectors with the highest growth of industry production in economy (1948 = 100)																	
Energy industry		100	165	360	639	718	967	1135	1220	1251	1276	1317	1370	1437	1473	1497	1527
Engineering		100	294	663	1201	1414	2118	2794	2925	3148	3306	3514	3718	3900	4056	4173	4203
Chemical industry		100	230	557	1257	1534	2428	3095	3189	3223	3362	3445	3608	3754	3873	3952	3980
The industry of construction materials		100	184	529	769	872	1202	1429	1486	1487	1492	1518	1542	1573	1607	1669	1673
Wood industry		100	192	342	484	544	774	982	1027	1072	1100	1140	1159	1193	1224	1254	1248
Glass industry, ceramics and porcelain		100	122	267	421	511	705	882	909	955	961	1003	1027	1046	1063	1128	1199

Source: Historical Statistical Yearbooks of ČSFR

[a]Kčs—Czechoslovak crown (national currency)

A similar development can be seen when comparing GNI per capita; the increase was almost double in the comparison of Slovak with the Czech population.

Nevertheless, the official national income growth stopped at the end of the eighties, having no more capacity to compete with the western economies. The former source of growth in industrialisation was over, and the first signals of coming de-industrialisation were apparent in the industrial statistics (Hudec and Šebová 2012).

Within the framework of socialist planning, the rapid industrialisation has been coupled with urbanisation in less developed regions, enforcing a large-scale industrialisation of the whole economy (Hudec 2009). The regional economies have not been growing and developing gradually, but industrial plants were artificially inserted externally into previously undeveloped areas. By way of comparison, in-dustrialisation of rural areas in the western countries was based on a light and in-tensive manufacturing industry. In the Central and Eastern Europe, rural industrialisation was a political target, and its mechanical implementation caused later vulnerability of those areas after the fall of the Berlin Wall.

2.3 Systems of Science, Technology and Innovation in the CEE Countries

The systems of science, technology and innovation in the CEE countries are not easily comprehensible because of their contradictory evolution and fundamental external interventions. Their current state can be understood only by discovering the roots after WWII and following influences.

The Comecon countries have agreed on a division of labour among different industries, including research and development. With an aim to exploit the advantages of large-scale socialist production, an international industrial specialisation and interconnection have led to setting up mutually complementary industrial structures. Altogether 78% of the Czechoslovak foreign trade turnover in 1985 (Gawdiak et al. 1989) was realised with the Comecon members and only 16% with so-called “developed capitalist countries”.

The authorities were later aware of the shortcomings of the economy giving low priority to research and development. A new dimension of technological capacity has been introduced in the early 1960s and gradually become a top priority also as an instrument to fight with more advanced capitalist countries. Each state has established a high-level central body (The Committee for Technology and Investment in Czechoslovakia). In the area of research and development, an ambitious “Comprehensive Program for Scientific and Technical Progress” up to the year 2000 was adopted in December 1985, aiming to interconnect and develop more efficient science and technology base. The plan included specialisation agreements, giving e.g. to Czechoslovakia a priority of research in the fields of automated production systems and robots or microelectronics in that time.

However, within the planning system, the approach was struggling to force innovations through administrative methods. Enterprise directors in the Comecon countries were not considered greatly innovation-minded (Wilczynski 1974), because of the high risk associated with innovations and serious repercussions if the venture is a failure. There was a big difference if the highest political leadership was involved in setting the technological goals such as a cosmic programme or military enjoying almost unlimited resources in the USSR. Also, a prevailing focus was on basic research and the extensive R&D system, "just as the crowd on the stage, produced paltry practical results" (Rabkin 1997). Although the mission of the applied research institutes was to introduce technological innovations to assigned peer industry, both parties had a low motivation for risky projects with a low success rate. In the end, the research institutes, having a little control over the implementation of their research results, acknowledged their situation and rather opted for a more comfortable strategy of fundamental research. With an aim to ensure their survival, they softly revised their priorities and readjusted their new outputs as scientific publications, doctoral theses, and other common products of basic research. The Soviet innovation culture has also been transmitted to Czechoslovakia and East Germany, the countries influenced by the German-speaking culture of research and innovation before, and more advanced in technology and innovation. The political strategy caused a re-orientation towards the Soviet innovation model and marked inclination to fundamental research also in Czechoslovakia. The Soviet model of Academies of Sciences, mostly divided from the innovation activities and focusing on fundamental research, have been promoted and established in all COMECON countries.

The hand of the central planning method can also be recognised in the development of the share of R&D employees on the total number of employees. In the last socialistic decade 1980–1989, the numbers are stable and well balanced for the Czech and Slovak parts of the country, but never exceeded 1.7% (Table 2). Only the proportion of R&D employees with a university education has been growing. Also, the number of R&D organisations was proportional to 2:1 population ratio: 207 firms located in the Czech part and 113 in the Slovak part of the territory. However, the big difference is in the number of R&D employees, showing Czech dominance of 70% in comparison to Slovak 30% share.

The general economic and technological backwardness and an artificial structural division explain the unpreparedness of the economies and research and technology sectors after their opening to global competition. That estimated labour productivity reached only 53% in Czechoslovakia in comparison to Austria at the end of the socialistic period. The economy was considerably more energy and raw material dependent, and technological level of the industry was lagging behind the world development by 10–15 years. Czechoslovakia was obviously first in the number of patents in the group of CEE countries until 1988, far behind followers were Bulgaria and Hungary (Lacasa and Giebler 2014). However, a strong decline in the patent intensity in Czechoslovakia started already in the 1980s. The transition process in the economy of Slovakia experienced the loss of foreign downstream markets of the former Eastern Soviet bloc. Moreover, the split of Czechoslovakia in 1993 has

Table 2 Structure of R&D employees in period 1980–1989

	1980	1983	1984	1985	1986	1987	1988	1989
Number of R&D employees	116,482	107,779	109,492	112,331	113,083	114,360	116,320	112,535
The share of R&D employees with university education	47.18	54.73	55.62	56.35	57.66	58.73	59.54	60.84
The share of R&D employees on the total number of employees in economy	1.53	1.44	1.45	1.48	1.47	1.47	1.49	1.44
Czech Republic								
Number of R&D employees	83,591	75,632	76,277	77,680	78,363	79,012	79,713	77,850
The share of R&D employees with university education	43.89	53.59	54.24	54.97	55.89	57.24	58.19	59.45
The share of R&D employees on the total number of R&D employees in CSSR	71.76	70.17	69.66	69.15	69.30	69.09	68.53	69.18
The share of R&D employees on the total number of employees in ČR	1.63	1.47	1.48	1.49	1.49	1.49	1.50	1.46
Slovak Republic								
Number of R&D employees	32,891	32,147	33,215	34,651	34,720	35,348	36,607	34,685
The share of R&D employees with university education	49.45	57.42	58.80	59.43	64.65	62.05	62.48	63.97
The share of R&D employees on the total number of R&D employees in CSSR	28.24	29.83	30.34	30.84	30.73	30.91	31.47	30.82
The share of R&D employees on the total number of employees in SR	1.44	1.38	1.40	1.46	1.42	1.43	1.47	1.39

Source: Historical Statistical Yearbook of ČSFR (1990) caused to a large extent also a loss of the research cooperation of the Slovak research and innovation workforce with the former team partners in the Czech Republic.

Following Kuznets (1965), the transformation of a country from underdeveloped into developed is not possible only by adding a stock of physical capital. It also must have a character of a thoroughgoing revolution in the life patterns, position of different groups and change in the relative powers. Also in the Slovak economy, profound institutional changes have resulted in a new vertical and horizontal organisation of the political and economic system, in different power relations among social clusters, etc. A complex process of decentralisation has also been implemented in Slovakia with an aim to bring decision-making closer to the citizens, to build democratic institutions at the regional and local levels and to activate involvement of local and regional actors in economic and social development.

In the centrally planned system of resource allocation, regional and city priorities and their financing were based on decisions at the national level, following a strict top-down approach rather. The system change has given the responsibility for local development and physical planning to "de novo" established municipal governments. Implementation of a new territorial system of decentralised governance has been one of the preconditions required from the candidate countries to access the European Union. At the regional level, rights and duties for development and planning were shifted to just recently formed or reformed regional administration. The legal autonomy of strategic planning and local economic development settled to regions and municipalities has not been accompanied by the corresponding financial resources from the government. The lack of resources at the regional and local level has resulted in fictitious strategic planning development. At one side, the financial handicap together with a lack of experience in strategic planning have caused setting their priorities analogously to the higher national level—the foremost potential sources of financing. The gifted privilege of economic planning in the first post-communist decades has got merely a form of strategic thinking training to prepare first planning documents.

Although the state has formally accepted devolution, in reality continues operating in terms of the centralistic system. On the other side, the previous top-down imperative exists in the paternalistic expectations of the subnational self-government institutions, making the state responsible for their less successful episodes.

3 The Rebuilding of National and Regional Innovation Systems in the Transition Period

3.1 Emergence of National and Regional Innovation System

The system is generally understood as a set of functionally interconnected elements, institutions, processes, flows and relationships between them (Skyttner 1996). Innovation has a central role in economic development, whether considered at the level of firm, industry, region or country. Accordingly, the innovation system can be defined as a set of economic and institutional relationships that occur in a geographical area (country, region), which is generating collective learning processes, enabling a rapid spread of knowledge and best practices (Hudec 2007a, b, 2010). Systemic and policy view of the innovation system is at stimulating innovation capabilities of firms and other economic agents in the geographical area (country, region) with an aim to boost the economic growth and competitiveness. The basis of the term innovation system is an assumption of both individual and collective dimensions of diffusion of knowledge and technology (Edquist 2001). Factors of technological changes are embedded not only in the activities of single enterprises, but also in other elements and relationships of the broader innovation system. Hence, innovation should be regarded in a context of the system, representing all its essential elements and relationships involved in the production, as well as dissemination and use of economically useful knowledge (Lundvall 1992a). Environment and institutions are considered as essential factors of uptake and diffusion of innovation; the national innovation system has, therefore, become an important part of national industrial policies.

National innovation system (NIS) and its regional subsystems constitute a systemic instrument and policy tool to increase the innovation capacity of an entity (country, region). However, national innovation systems are not always built so as to take regional interests into account. The uneven pattern of innovation geography is implicitly suggesting the importance of the role of proximity, the density of the institutions and networks in a diffusion of knowledge and drawing attention to subnational regional units (Iammarino and Mccann 2013). In the same manner, like NIS, the emphasis of Regional innovation system (RIS) is on the processes of generating knowledge and its distribution through linkages and networks. The regional innovation system, however, is much more complex to understand and evaluate than national, sectoral or technological levels. The region itself can be regarded as a complex spatial dynamic open system (Hudec 2007a, b). The interactions between the business sector and other agents of the economic system, the types, and intensity of the relations vary according to many factors (Asheim et al. 2011). In most of the definitions (Cooke and Memedovic 2003; Asheim 2007), RIS consists of two fundamental parts: regional production structure (large and small companies) and regional supportive infrastructure (universities, research institutions, technology transfer agencies, business associations, finance institutions and institutions providing public and private innovation services).

What matters for innovation performance, is not only the administrative, financial and technological institutional framework and institutional density. Other important differentiating variables of the RIS are industrial and knowledge base structure, geography, spatial structure, scale and degree of urbanisation. Evolutionary economics view is important to understand specific local institutional factors such as social norms and routines, trust, informal rules, shared norms of cooperation, untraded interdependencies, interactive learning, relative powers, the density of social networks and their employment as channels for informal knowledge diffusion, etc. All the complicated set of factors of knowledge diffusion, institutional interlinkages and embedded innovation culture define specific territorial externalities, either providing incentives or obstacles to innovation.

Geographical proximity is increasingly mainstreamed as an indispensable condition to share tacit knowledge, in the networks and to enhance trust between innovators (Torre 2008). Hence, there is a question, which is later studied on the example of the Slovak inventory networks, how important is geographical proximity for innovation?

The current CEE variant of the national innovation system is built on the previous structure of centralised science and technology system. That was top-down directed and focusing on sectoral industrial relations, overlooking the importance of intra-regional and inter-regional horizontal networks (Hudec 2007b). The national science and technology systems were financed both from the state budgets and at the same time by means of mandatory allocations into R&D by industries. By the late 1980s, the collapsing economy of COMECON was no more able to keep the research system of the current size (Rabkin 1997). The COMECON organisation of the communist countries dropped to a minimum level and started to build concurrent cooperation with West-European countries (Gál and Rácz 2008; Hudec 2009).

Breakdown of the previous centralised vertical structure, denationalisation and privatisation during the transition period had a significant impact on regional economies, resulting in rising regional disparities and rather different regional development trajectories, including research, development and innovation. The elements of Western European innovation system models have been introduced into still centralised research and development modes of operating, resulting in diverse variations of regional innovation systems. Since the early 1990s, European Commission has built up broad institutional and financial support to implement strategies and measures in favour of weakly developed regional innovation systems. EU supported establishing of innovation centres and agencies and development of regional innovation strategies and operational programmes in the CEE regions.

Unfortunately, after almost 30 year period of the reintegration into European economy, CEE regions display a low level of cooperation between triple helix entities (knowledge institutions, industry and public authorities), poor patent performance and unsatisfactory generation, transfer and exploitation of knowledge. There is a clear conflict between the newly formed regional institutions, including self-government regional administration responsible for regional development, and a persistent continuing tendency of central, vertical decision making. Decentralisation of rights and duties has happened without providing appropriate financial and economic instruments, and there is widespread scepticism in the society towards the capacity of local and regional authorities (Hudec and Urbančíková 2008).

Not surprisingly, both centrality and the supremacy of vertical flows in the governance of the innovation system are vivid in the regional innovation policy implementation as well. The EU enforced regionalisation and decentralisation of power, and resources have been expected to have a form of regional innovation policies towards supporting competitiveness for firms with an emphasis on networking among regional actors. The national government, however, is reluctant about the intensification of research, development and innovation support in less favoured regions. On the other hand, less innovative regions do not have a sufficient absorption capacity for eventual incentives.

The EU regional innovation policy highlights change of the regional governance system towards more networking structure, embedding together cooperation and competition, in a battle with resistant old science and technology national and sectoral hierarchical structures. The modern European innovation policy instruments are in an apparent conflict with the continuing functioning of science and technology system of COMECON period. Transfer of regional innovation system instruments (innovation centres, innovative enterprise incubators, science parks, technology and knowledge transfer centres) are hindered by both formal and informal propensity to central, vertical decision-making culture. The weak, unstable and fragile regional innovation systems in Slovakia are dominated by the prevailing national science and technology system, maintaining separated roles of business, universities and academy of sciences. EU driven innovation instruments are in a serious fight with the national sectoral science and technology policy, previous models of knowledge generation and diffusion mechanisms focusing mainly on fundamental research, etc. Furthermore, the post-socialist development suffers from the disintegration of the former innovation networks, looking for a new balance of international and domestic collaboration. The result is rather mixed and incomprehensible model of regional cooperation triple helix, usually unable to establish a common language in the innovation networks. This situation gives a motivation for a deeper study and understanding of regional innovation networks, providing a multifaceted view of the Slovak regions and understanding the keystones the of their weak innovation performance.

3.2 Transition of the Science and Technology

Patents are granted to inventors for inventions which are novel, innovative and nonobvious and also useful, having an industrial application. They are considered as a large pool and comprehensive source of data on innovation activities and technological change (Hall et al. 2005) and their advantage is undoubtedly a detailed information and description on the innovation. This explains a popularity of the patent statistics use in the research of innovation performance (Griliches et al. 1991). It is evident; there is a limitation of patents in relation to innovation, as not all the innovations are registered in the patent databases because of several reasons (Koh and Reeb 2015). Not all inventions fulfil the necessary requirements of the patent office, the process is long and administratively burdensome, involves cost. A further loss of the registered patents arises if the inventor relies on secrecy or underestimates the role of intellectual property protection.

Completeness of a dataset of the innovation activities is impossible for the pre- and transition period of Slovakia. However, the patent activity can be used as a proxy variable to identify evolutionary aspects of innovation activity development. The institutional analysis of the patent statistics (Slovak Patent Office of Industrial

Table 3 Number of institutions applying for patents in 1988–2012

	1988–1992	1993–1997	1998–2002	2003–2007	2008–2012
Universities	10	8	10	7	7
Applied Research Institutions	26	8	6	3	4
Institutions of Slovak Academy of Sciences	26	13	9	12	11
Enterprises with 3 or more patent applications	33	20	19	18	15
Enterprises with <3 patent applications	103	113	95	87	91
Overall	198	162	139	127	128

Source: own

Rights) shows the decline of the patent activity after the fall of communism in Slovakia during following 25 years in 1988–2012 (Table 3). The number of institutions applying for patents is divided into five periods of 5-year intervals.

The first finding is the total number of institutions, which is decreasing over the whole period from 198 to 128, meaning one-third loss in the number of active institutions and showing no signs of recovery. The main loss of activity is evident in the category of applied research institutions, losing stepwise the support of industry associations and disintegrated industrial structure. Institutes of the Slovak Academy of Sciences and universities have also lost their initial patent performance. Moreover, originally innovation-active enterprises have submitted fewer applications or did not survive in the competition. In contrast to more frequent enterprise patentees, the group of enterprises with less than three patent applications constitutes a major part of all innovation actors over the whole period, but they usually applied for patents only once and then disappeared from the Slovak patent market. Such enterprises are usually incidental single applicants with closed research teams (inventors), having no external research cooperation.

Institutional analysis indicates in this way not only explicit downturn in patenting activity but also fragmentation of the networks of inventors in Slovakia. The disintegration of the main cluster component of the cooperating institution and the increasing share of isolated research is reflected later in the study of the innovation networks.

As could have been expected, the transition of the economic and political system in Slovakia (and other CEE countries) necessarily had to affect also innovation activity in terms of number of patenting institutions, the intensity of patenting as well as size and density of the networks of inventors. The intensity of patenting activity (as the number of patent applications) is displayed in Fig. 1, showing the patenting development of the most important single universities (labelled U1–U6), research institutes (RI), the Slovak Academy of Science (SAoS) and the group of enterprises with 3 and more patent applications in a particular 5-year time period (E). With the exception of the Technical University of Košice—TUK-U8, the fall is evident after the year 1993, the first year of independent existence of Slovakia.

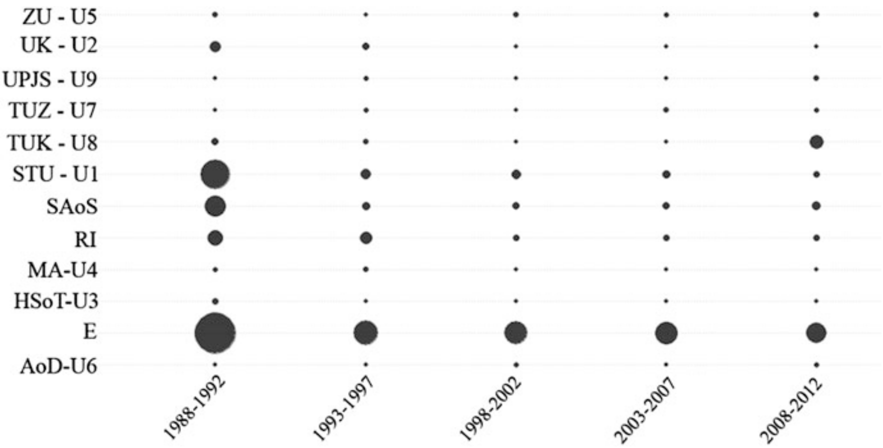

Fig. 1 Patenting activity of institutions in 1988–2012. Source: own

Czechoslovakia in the communist era was spending massive sources on defence and was among the top ten largest arms exporters in the world (Hardt and Kaufman 1996). Dual structure of the economy consisted of a strong military sector and a weaker civil sector. Duality inhibited spin-off effects from the military sector, hindered knowledge transfer and self-propagating virtuous circle between military and civilian technologies (Chiang 1990; Radosevic 1999). Typically, in many firms, concurrent military and civilian R&D and production co-existed in separated parts, but the diffusion of knowledge from military to the civil sector was not desired. Ever-present strict control of information and hierarchical vertical central planning have caused a kind of silo effect in science and technology, separation of R&D institutions from market and production. According to the socialist science and technology model, R&D was externalised, "in hands" of "science and scientific services" sector (Radosevic 1999) and technology was a commodity for trading. In other words, R&D was organised for industry, not in the industry (Radosevic 1996) and this fact is probably one of the main problems of later adaptation of Slovak businesses on new demand conditions in a market economy (inability to support own R&D and decreasing in patenting activity—Fig. 1).

Slovak enterprises are typically small or medium-size firms with low knowledge intensity and limited access to external financial sources. Only few large enterprises were applying for patents during the whole period. Table 4 shows the number of patent applications according to NACE sections in the period 1988–2012. The branches of mechanical engineering and chemical industry accounted for the highest growth in the Czechoslovak post-war economy (Table 1), and accordingly the greatest number of Slovak institutions applying for patents can be found in the same fields in the period 1989–1992 (Table 4). As already highlighted in Table 3, the number of patenting institutions has been decreasing, and the branch structure of the patents remains stable.

Table 4 Distribution of patent applications in 1988–2012 (Number of institutions in different fields of technology)

	1988–1992	1993–1997	1998–2002	2003–2007	2008–2012	Overall
Section A—Human Necessities	35	31	23	12	22	123
Section B—Performing Operations; Transporting	47	36	31	28	21	163
Section C—Chemistry; Metallurgy	63	55	54	47	39	258
Section D—Textiles; Paper	3	2	1	1	4	11
Section E—Fixed Constructions	14	7	11	4	15	51
Section F—Machine Engineering; Lighting; Heating; Weapons; Blasting	21	21	18	23	18	101
Section G—Physics	29	17	10	18	19	93
Section H—Electricity	17	11	7	8	21	64

Source: own

4 Evolution of the Regional Networks of Inventors

4.1 Networks of Inventors

At the end of the 90ties, new concepts emphasizing the systemic nature of innovation appeared as an approach of regional innovation systems (Cooke et al. 1997), taking into account the geographical proximity, as well as the concept of technological (Carlsson and Jacobsson 1997) and sectoral systems (Malerba 2002). All the three new concepts are usually presented as alternatives to national innovation systems, highlighting the dimensions of the region, technology branch or sector, and offering cross-cutting and cross-border views, and revealing limitations of the simplified notion of the national innovation system. However, the national view is critical if the political dimension of the concept of innovation systems is stressed (Lundvall 1992b). Findings with regard to knowledge, learning processes and interactions of different agents are placed at the forefront of research factors such as knowledge, networks and co-evolution processes. These factors are likely to create conditions boosting generation of innovation. Therefore the following research is aimed at analysis of the networks of inventors, which is understood as a part of the innovation system, and builds on the theoretically expected flows of knowledge between innovation actors.

The systems approach assumes that economic performance of an area (region or country) does not depend only on business performance, but also on the interactions between innovative actors in the public sector in terms of production and dissemination of knowledge. Innovations can be understood as a result of cumulative processes that are affected by institutional settings (Fischer 2001). Inventor networks are usually monitored through patent applications (Graf and Henning 2006; Cantner and Graf 2006; Fritsch and Graf 2011; Miguélez and Moreno 2013). Using patent applications and network analysis relates to the narrower definition of innovation. Analysis of innovation networks is mostly applied to regional level, as intra-regional linkages and proximity remain relevant despite the current era of globalisation. The innovation ability depends on the access to "invisible factors of production" (non-codified knowledge, sticky information) that is easier to get through the existing links in networks. Regional networks improve access of SMEs to regional knowledge. However, their true strength lies in linking to global networks. In the approach of this chapter, the links are also classified as intra-regional and inter-regional relations, to understand the importance of proximity and external links to region.

Evolution of the system leads to a growing concentration of actors in the network; the actors are clustered around key players. A critical mass of innovation actors and their collaboration is essential to the survival of specific technologies in the local system. In contrast, regions with a strong knowledge base (characterised by broad technological areas), are typical by a more fragmented network of innovators (Cantner et al. 2010). One of the main problems is to achieve cooperation between different actors, which supposedly leads to the generation of the desired output—new knowledge, innovation, economic and social benefits in a region). The actors of the innovation system have their own expectations regarding the behaviour of other parties (Belderbos et al. 2014). Reluctance to enter into partnerships of inventors also relates to the problem of appropriating the benefits arising from a common patent.

Data obtained from the database of patent applications are principally relational data (data indicating relations between entities and individuals), and social network analysis (SNA) can be used for their analysis, bearing in mind actors (nodes) present in the network and common patenting as links (edges). Once we have the adjacency matrix (matrix of relations between the inventors), by the SNA method can be expressed the size and density of the relationships, the centrality of the networks, the number of pairs or triples, diversity of the network patterns, and many other network-based properties.

Inventory networks in Slovakia are studied based on the long period from 1988 to 2012 to watch the transformation of socialistic Slovakia to a market economy. In the case of Slovakia, most of the institutions apply for patents at home (institutions registered as applicants under Slovak Office of Industrial Property). In such a case thereafter do not apply for patents under EPO or WIPO[2] or they applied for patents on the international markets only a few times. The number of patenting institutions as well as patent applications has been decreasing after 1989, and the loss of ties with the former Eastern markets and split of the Czechoslovakia should also affect the number and density of the innovative networks.

This justifies the hypothesis of a progressive fragmentation of inventory networks in Slovakia and a decreasing rate of cooperation due to transition. However, after 25 years, new stimuli for networking related to growth of the Slovak economy, integration to European economy and implementation of European regional innovation policies should result in a renewal of remaining linkages between the actors as well as to bring into patenting pool new actors and their interconnections.

The research required to collect data registered in the patent applications for the period 1988–2012 from the website of the Industrial Property Office of the Slovak Republic. The process of collection was rather complicated, as the information on each patent application exists only in a pdf file and no possibility to obtain XLS or CSV format data existed. In total, 28,510 patent applications have been reached with information on 48,170 inventors. All patent applications contained information on the names of the patent applicants, the names of inventors, addresses, description of the invention, patent classification, the state of the patent application (published in the proceedings, suspended grant, refuse), etc.

The decline in the size of inventory teams is visible in Fig. 2, visualising the gradual degradation of the main components and the creation of fragmented and crushed networks. Decomposition of the main component (the core network) is caused by the disappearing of some links, meaning completion of the former cooperation between two actors, or disappearance of actors with their links (star-type graphs of the node and the set of its edges).

The Fig. 2 recounts visual patterns of the fragmentation and disappearance of the former networks. A lower average degree of nodes (average number of links), breakdown of the main components and increasing proportion of isolated actors, of course, mean much less interest in cooperation between the innovation actors and weak national and regional innovation systems.

Connections among inventors in the first period 1988–1992 form more developed networks than in the later periods in terms of higher mean degree and a lower share of isolates. In comparison to inventory network in the first period, the number of edges (links) decreased by around 64% in 1993–1997. The overall number of innovation actors (nodes) has been decreasing gradually. Hence, a structural hole in the evolution of inventory networks can be identified after 1993. It could be assumed that networks would be more developed (with more links/edges) after opening the economy and markets to innovative foreign companies, inventory networks are more and more fragmented over the time. This is, however, not the case, a potential innovation output realised in Slovakia is assigned to foreign countries (Lengyel et al. 2013). Domestic enterprises are usually small and medium

[2]These institutions are not registered like appliers under the ESPACENET database which includes EP (European published applications) database and WIPO (PCT published applications) database

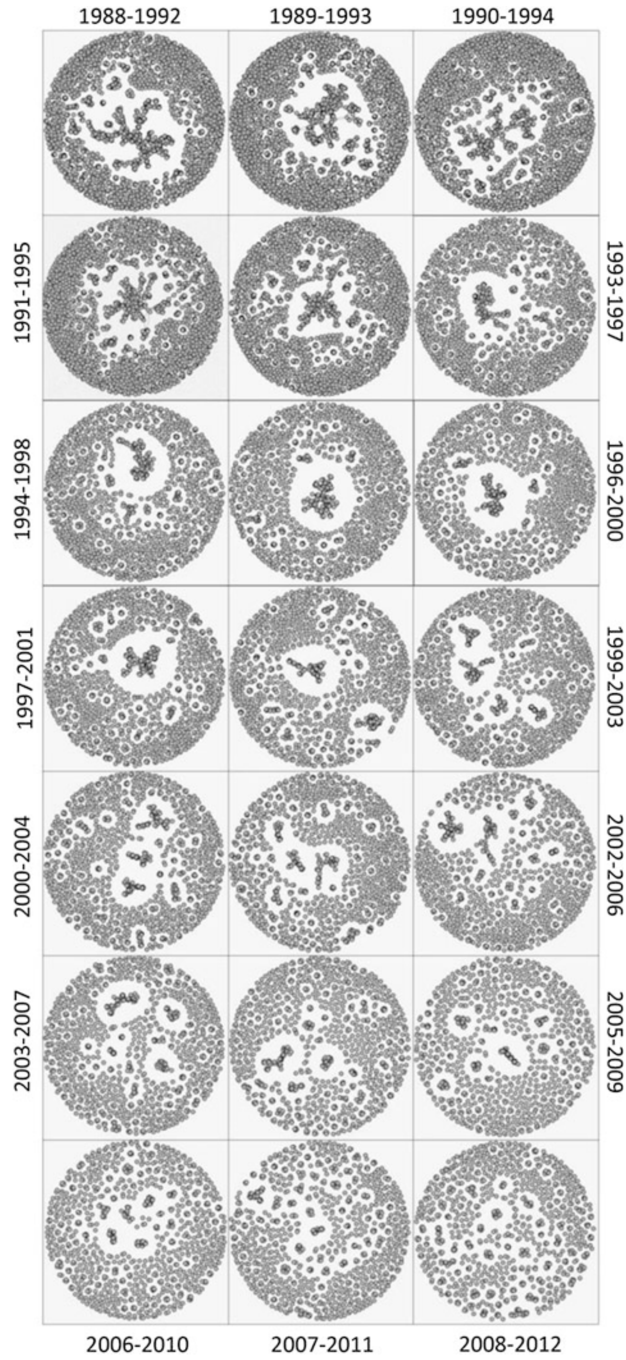

Fig. 2 Networks of inventors in Slovakia—1988–2012. Source: own

size firms, characterised by lower knowledge intensity and limited access to external funds.

The loss of actors and ties highlights the growing dependence of the Slovak economy on foreign inventions. The massive entry of foreign investors has influenced domestic innovation capacity in a rather negative way, as their research and innovation units are typically not located in Slovakia (Morvay 2013; Smith 1998). The local researchers have either relocated abroad or work in Slovakia as members of the research teams located and led out of Slovakia. Both models usually contribute to eventual patent applications in a country of investor origin.

The maturity of inventory networks is analysed with the help of network properties: the number of patent applications, the number of nodes, number of links, network density, the average node degree, centrality of the network, the number of components in the network, the number of nodes and links forming the main component, the average distance between the nodes of the main components and the proportion of isolated actors.

Also, the level of inter-regional and transnational cooperation is analysed. The individual innovative activity is defined as the number of patent applications in which an individual inventor is involved. The total number of patent applications representing a network innovation activity is assigned in a similar way to a network of inventors. Involvement in the networks (both within the country or region, inter-regional and transnational) is a measure reflecting the innovation activity of an innovation system.

Inventors (institutions or individuals) correspond to nodes of a regional inventory network, the edges between nodes correspond to at least one common patent application. The number of actors involved in the whole period in the patent applications is n. The relational data express the relationships between the pairs of inventors in the form of links, and the number of links corresponds to the number of pairs of actors which occurred together as partners in at least one patent application. A maximum possible number of links is $n(n - 1)/2$. A node is assigned to a region if at least one inventor on a patent application is its resident. The analysis of the inventory networks is based on additional characteristics of the networks as defined in the graph theory (Cohen and Havlin 2010):

- **The edges/nodes ratio** is defined as the number of edges divided by the number of nodes; the value varies between 0 and the maximum value of is $(n - 1)/2$.
- **The number of components and the size of the main component**: connected components are sub-graphs in which any two nodes are connected by a path of the unbroken links. The connected component represents a group of actors who are interconnected directly or via other actors in the component. The main component is comprised of the largest number of linked actors (Hanneman and Riddle 2005).
- **The share of the main component (%)**: percentage of the number of nodes contained in the main component. A proper interconnection between the actors should be evident by a large share of main component of the cooperating actors.

- **Intraregional, interregional and transnational dependence**: the indicator is determined as the share of the inventors having their address outside the region or abroad.
- **The average distance in the main component**: distance between two nodes is the number of links on the shortest possible path from one actor to another. In a dense and connected network the shortest distance between two actors is low, reflecting the relatively rapid flow of information. As the monitored networks are not fully connected, the analysis deals only with the average distance in the main component only.
- **Number of isolates and share of isolates (%)**: the isolates are actors with no any patent cooperation. The high percentage of isolates reflects the existence of a group of single actors outside of the innovation system environment.
- **Centrality**: the value of *CD(n*)* identifies the most important node within a graph, involved in the largest number of interactions, i.e. the most prominent institution or individual in a whole network, a key innovator or accelerator of the innovation performance. An individual degree centrality is defined as the number of links incident upon a node and the whole network centrality is $\boldsymbol{C_D} = \frac{\sum_{i=1}^{g}[\boldsymbol{C_D}(\boldsymbol{n}^*) - \boldsymbol{C_D}(\boldsymbol{n_i})]}{\max\sum_{i=1}^{g}[\boldsymbol{C_D}(\boldsymbol{n}^*) - \boldsymbol{C_D}(\boldsymbol{n_i})]}$.
- **Density of the network**: If n indicates the size of the network (number of nodes) and d_i the number of connections passing through the node i, $(i = 1, \ldots, g)$, the network density D of the network is defined as the ratio of the total number of edges (links) in the network to the total number of all possible edges: $D = \sum_{i=1}^{g} d_i/\left(g^2 - g\right)$. The density of the network reflects the diffusion of information between nodes, or the extent of the social capital within a network. Denser, interconnected networks are able to mobilize their resources more effectively, as well as to address emerging issues (research questions) in different ways (Hanneman and Riddle 2005).
- **The degree of a node and average node degree**: the measure of the number of direct links of a given actor. The higher the average node degree across the whole network, the greater it's power to create mutual innovation-based relations between the actors.

  Actors having more links compared to others have an advantageous position, as more links mean more alternative ways to ensure their needs. Thanks to their advantageous position, they act as intermediaries of knowledge within their networks.

The set of network characteristics can serve to monitor the extent, density, centrality and other qualities of cooperation among innovation actors within the country or regional innovation systems. The following Table 5 depicts the development of network density, network centrality and evolution of the number of edges in the number of nodes. First, the decline in the number of nodes is apparently stabilised at around 1000 actors, which is about 30% lower than at the beginning of the period. Even greater is the loss of connections. Cooperation on patent applications is much smaller, the number of connections decreased from 4545 in 1988–1992 to a little over 1000 in the last 5-year periods. Declining cooperation tendency is captured by the edges/nodes ratio.

In Slovakia, the R & D exhibits structural gap. Old companies have ceased their original innovation activities, while new institutions potentially replacing the original inventors are sporadic. In comparison to period 1988–1992, the number of edges (links) in the period 1993–1997 decreased by about 64%. The loss in the number of connections led to fragmentation of the whole innovation system. In the beginning, the main component consisted of 507 members, but at the end, it counted only 28 members. In the period 1992–1996, altogether 15% of actors disconnected from the main component and after separation from the Czech Republic, the next 27% of actors have left the main component. In the period 1997–2001, nearly 40% of new actors with at least 5 links appeared. However, this new research teams form only a small number of links (maximum 10).

Fragmentation is a huge problem, as the dominance of small groups of inventors, increasing proportion of the isolated actors, and undermined relations inside the system indicate low functioning innovation system. The network analysis also confirms the low level of social capital in relationships, lack of trust and so far poor results of the new innovation policy. Hence, an urgent focus of innovation policy in Slovakia should be on building trust and links and to overcome present fragmentation, and to bring new actors onto the national innovation stage. Another way of improvement exists in the concentration on the regional innovation systems, which are studied in the following subsection.

4.2 Regional Networks of Inventors

A more detailed view on the knowledge production process can be explained by analysis of the regional inventor networks. The importance of geographic proximity shifts the attention to regional level towards regional innovation systems (Cooke et al. 1997; Doloreux and Parto 2005), mainly due to limits of non-codified knowledge transfer.

In the socialistic period, Central and Eastern European countries have advocated linear innovation approach with a limited horizontal cooperation (Godin 2006). These hierarchies led especially Czechoslovakia to the integration of the whole branch including R&D into one concern and to limited cross-branch cooperation (Von Hirschhausen 1999; Radosevic 1999). Regional horizontal economic relations were not in the focus of the central planning.

Fritsch and Graf (2011) analysed how different history and macroeconomic conditions shaped regional innovation activities. Their findings for the East and West Germany indicate significant structural differences between their innovation networks. Also in the case of Slovakia, a long time series of the statistics of patent applications makes possible to evaluate the path dependence and evolutionary dynamics of the regional inventory networks. Deindustrialisation particularly

Table 5 Networks characteristics—inventors in Slovakia 1988–2012

Slovakia	*1988-1992*	*1989-1993*	*1990-1994*	*1991-1995*	*1992-1996*	*1993-1997*	*1994-1998*	*1995-1999*	*1996-2000*	*1997-2001*	*1998-2002*	*1999-2003*	*2000-2004*	*2001-2005*	*2002-2006*	*2003-2007*	*2004-2008*	*2005-2009*	*2006-2010*	*2007-2011*	*2008-2012*
Number of patent applications:	1364	1544	1577	1502	1478	1176	1124	1091	1083	1135	1180	1165	1163	1080	1027	1008	967	937	1030	1059	986
Number of nodes:	2393	2544	2428	2200	2080	1616	1483	1417	1364	1404	1346	1350	1336	1302	1210	1174	1109	1032	1094	1124	1124
Number of edges	4545	4563	3899	3285	2920	2091	1863	1797	1873	1849	1815	1843	1830	1772	1642	1464	1318	1111	1216	1363	1475
The edges/nodes ratio	1.899	1.794	1.606	1.493	1.404	1.294	1.256	1.268	1.373	1.317	1.348	1.365	1.370	1.361	1.357	1.247	1.188	1.077	1.112	1.213	1.312
Number of components	704	790	821	800	813	695	669	645	620	640	619	617	608	580	544	565	545	530	543	529	485
Size of the main component	507	440	376	309	217	147	149	165	148	150	97	79	70	56	104	72	66	41	28	36	28
Share of the main component (%)	21.19	17.3	15.49	14.05	10.43	9.097	10.05	11.64	10.85	10.684	7.207	5.852	5.24	4.301	8.595	6.133	5.951	3.973	2.559	3.203	2.491
Average distance in the main component[a]	6.458	5.624	5.957	6.031	4.802	4.208	3.770	3.408	3.261	3.476	3.199	3.232	3.401	3.677	3.338	3.195	3.156	2.301	1.880	2.313	2.235
Share of isolates (%)	12.45	13.99	16.39	18.91	21.73	25.06	26.9	27.03	27.57	27.564	28.97	28.07	28.59	26.65	27.69	30.49	31.29	31.98	30.71	29.45	25.98
Number of isolates	298	356	398	416	452	405	399	383	376	387	390	379	382	347	335	358	347	330	336	331	292
Centrality[b]	0.025	0.022	0.018	0.015	0.015	0.020	0.026	0.029	0.026	0.028	0.026	0.023	0.020	0.019	0.028	0.020	0.022	0.021	0.017	0.013	0.018
Density	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.0019	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Average node degree	7.597	7.175	6.423	5.973	5.615	5.176	5.025	5.073	5.493	5.268	5.394	5.461	5.479	5.444	5.428	4.988	4.754	4.306	4.446	4.851	5.249

Source: own
[a]Based on the average shortest path
[b]Based on degree centrality

Table 6 NUTS3 regions in Slovakia

NUTS code	The name of the region
SK042	Košice region
SK041	Prešov region
SK032	Banská Bystrica region
SK031	Žilina region
SK023	Nitra region
SK022	Trenčín region
SK021	Trnava region
SK010	Bratislava region

Source: own

affected sectors and regions with poor ability to respond to rapid liberalisation. The main factors of the decline of regional economies in 90ties were rapid industrialisation, regional dependence on single large enterprise, a one-sided industrial structure with a concentration of the armaments industry, heavy engineering, mining, steel or chemical industries. For the regional innovation focus, Slovakia is divided into eight NUTS III regions (Table 6).

Figure 3 depicts the development of the regions using the network indicators defined in the previous subsection. The size of the circles reflects the values of particular network characteristics to compare the regional evolutionary dissimilarities. The decrease in the number of inventors is general, ongoing in all regions. Typically, only a few regional enterprises ensure patenting activity, and similarly, the number of patent applications is going down, with the exception of the Košice region. In the Bratislava region, the number of inventors in the main component decreased during 20 years by 94% (from 377 inventors in 1988–1992 to only 23 in 2008–2012).

In the Bratislava region, there are more than 55% of all employees of science and research, which shows a regional imbalance in the distribution of R&D human resources. Therefore, it is necessary to examine the Bratislava region separately, as it is critical for the overall country innovation output. Decreasing size of the research teams is shown on Fig. 4 and Table 7, displaying dismantling of the main component. In the beginning, there were 1232 inventors creating 2739 links in the Bratislava region, while in the last period only 469 inventors with 747 links in the patent applications. The capital region of Bratislava shows similar pattern of development as the whole country.

In comparison to the country level, regional focus gives a possibility to find out new evidence on the intra- and inter-regional links, as well as the transnational cooperation (Table 7). The principal economic and R&D centre of the country provides only a little impetus to other regions, having 68% intraregional partners within the Bratislava region.

One-quarter of the existing partnerships in patent applications is inter-regional, mostly with the neighbouring regions in the west of the country. Transnational

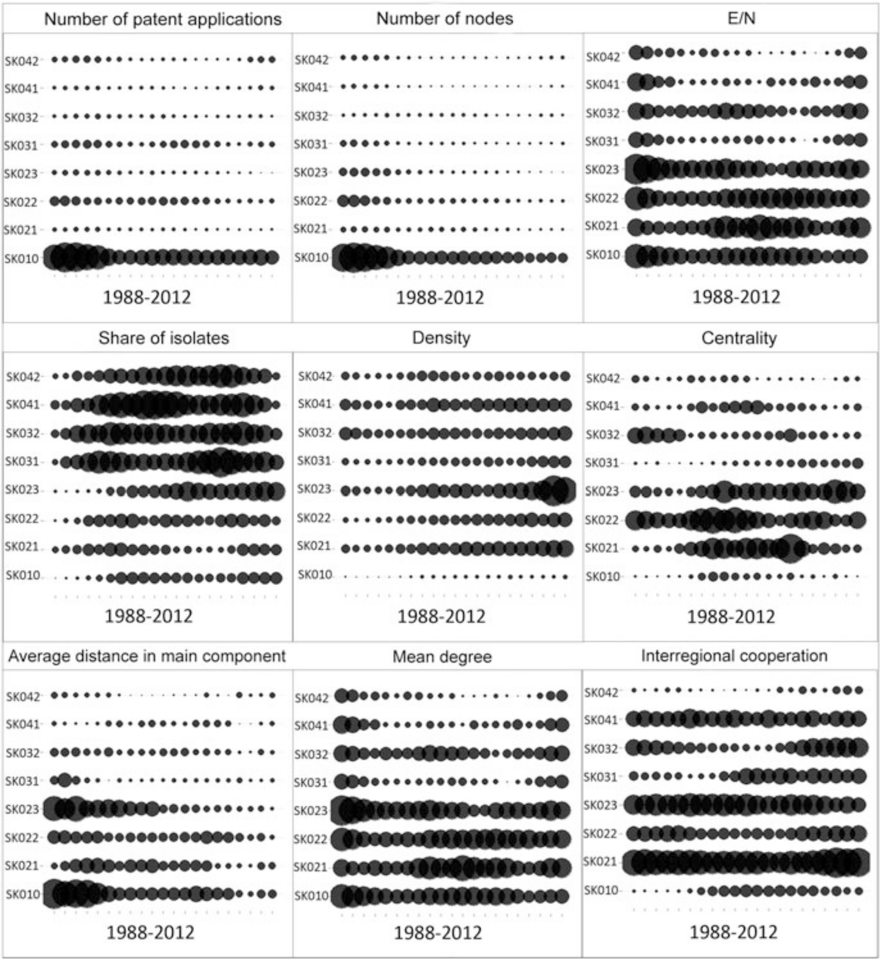

Fig. 3 Network properties of the 8 Slovak regions (NUTS3) in 1988–2012. Source: own

cooperation has not been well developed before, and it is still decreasing. Although the economy is open, the innovation sector continues in the previous path of separated science, education and business, having only formal relations in the triple helix innovation system. Most of the institutions are living in the comfort zone of publicly financed fundamental research and using European structural funds for non-registered intellectual property products. Only Žilina region did not undergo decomposition of its regional networks (Fig. 5).

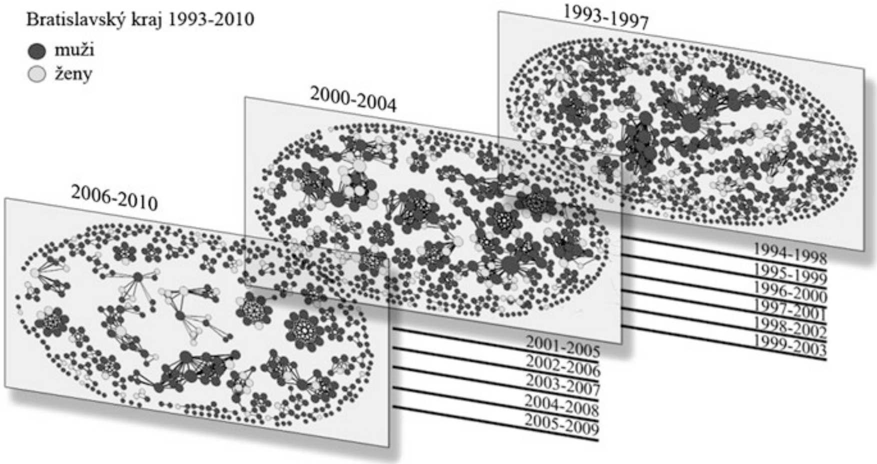

Fig. 4 Networks of inventors in Bratislava region 1993–2010. Source: own

5 Conclusions

The number of inventors in Slovakia decreased more than 50% during the 25 year period... During the period 1988–2012, almost all organisations (universities, research institutions, Slovak Academy of Science and enterprises) suppressed their patent activity, and the largest decline was found after the year 1993. Fragmentation and decline in the inventory networks suggest structural hole in the innovation network evolution in Slovakia. This structural hole is mirrored in the disintegration of research teams which have not been replaced by new research networks.

The innovation systems, whether national or regional, are underdeveloped and lack the main substance—well-functioning linkages between the actors. Creation and diffusion of knowledge, skills and best practices are not well used and established. A later small increase in the number of patent applications is not accompanied by an appropriate increase in the number of inventors. The share of single inventors—individuals who are also appliers on the patent applications is higher in the last periods in comparison with periods of Slovak transformation. An indication of unleashing the innovation potential can also be found in a slightly increasing cooperation among a smaller number of inventors. Regional networks of inventors, if formed, are mostly star-shaped clusters (all actors are connected to one central inventor), less usual are triangles or dyads.

Inter-regional dependence shows dominant position of the west and east Slovakia centers—Bratislava and Košice. Cooperation or dependence in innovation networks exists on the side of six regions in relation to Bratislava and Kosice regions, although the highest proportion of the links exists within the regions showing the greatest importance of the regional than national innovation systems. The decrease in the patent performance has also been caused by the split of Czechoslovakia and

Table 7 Networks characteristics—inventors in Bratislava region 1988–2012

Bratislavský regiốn SK010	1988-1992	1989-1993	1990-1994	1991-1995	1992-1996	1993-1997	1994-1998	1995-1999	1996-2000	1997-2001	1998-2002	1999-2003	2000-2004	2001-2005	2002-2006	2003-2007	2004-2008	2005-2009	2006-2010	2007-2011	2008-2012
Number of patent applications:	599	694	685	620	575	417	352	356	369	385	400	403	400	380	362	369	379	368	376	385	335
Number of nodes:	1232	1304	1238	1102	1010	739	616	593	607	628	606	614	602	604	567	542	526	465	471	485	469
Proportion of women actors (%)	17.13	17.33	17.93	17.88	17.33	15.29	14.29	14.17	13.67	14.809	15.68	16.78	16.61	19.7	19.75	18.45	16.54	16.77	14.86	15.46	14.71
Proportion of men actors (%)	82.87	82.67	82.07	82.12	82.67	84.71	85.71	85.83	86.33	85.191	84.32	83.22	83.39	80.3	80.25	81.55	83.46	83.23	85.14	84.54	85.29
Intraregional cooperation(%)	68.91	70.71	71.97	71.78	71.88	71.18	68.67	64.92	64.09	65.605	63.2	64.01	65.28	64.24	65.26	66.05	64.83	65.59	64.33	67.84	67.38
Interregional cooperation (%)	20.62	20.02	19.22	19.6	20.79	22.87	25.65	28.84	29.65	29.618	31.68	30.94	30.23	30.63	29.28	28.97	29.47	27.31	28.66	25.57	25.8
Transnational cooperation (%)	10.47	9.279	8.805	8.621	7.327	5.954	5.682	6.239	6.26	4.7771	5.116	5.049	4.485	5.132	5.467	4.982	5.703	7.097	7.006	6.598	6.823
Number of edges	2739	2735	2389	1982	1695	1167	981	979	1095	1102	1107	1152	1119	1071	1038	966	847	669	705	745	747
The edges/nodes ratio	2.223	2.097	1.93	1.799	1.678	1.579	1.593	1.651	1.804	1.7548	1.827	1.876	1.859	1.773	1.831	1.782	1.61	1.439	1.497	1.536	1.593
Number of components	273	310	314	303	297	249	222	216	219	225	207	209	200	197	179	181	186	179	177	179	170
Size of the main component	377	329	290	244	149	92	93	121	112	117	71	68	56	48	65	57	49	27	25	27	23
Share of the main component (%)	30.6	25.23	23.42	22.14	14.75	12.45	15.1	20.4	18.45	18.631	11.72	11.07	9.302	7.947	11.46	10.52	9.316	5.806	5.308	5.567	4.904
Average distance in the main component[a]	6.266	5.525	6.004	5.905	4.753	3.645	3.075	3.062	2.996	3.0718	2.988	3.05	3.117	3.664	3.262	2.956	2.873	1.981	1.706	2.211	2.28
Share of isolates (%)	7.792	9.126	10.34	11.89	13.66	15.97	18.83	19.06	18.45	17.994	17.49	17.59	17.44	15.89	15.34	16.42	16.35	19.14	18.47	18.97	18.98
Number of isolates	96	119	128	131	138	118	116	113	112	113	106	108	105	96	87	89	86	89	87	92	89
Centrality[b]	0.028	0.024	0.021	0.027	0.028	0.035	0.05	0.059	0.057	0.0504	0.045	0.046	0.039	0.037	0.048	0.032	0.034	0.028	0.038	0.027	0.021
Density	0.004	0.003	0.003	0.003	0.003	0.004	0.005	0.006	0.006	0.0056	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.007
Average node degree	8.893	8.39	7.719	7.194	6.713	6.317	6.37	6.604	7.216	7.0191	7.307	7.505	7.435	7.093	7.323	7.129	6.441	5.755	5.987	6.144	6.371

Source: own

[a]Based on the average shortest path

[b]Based on degree centrality

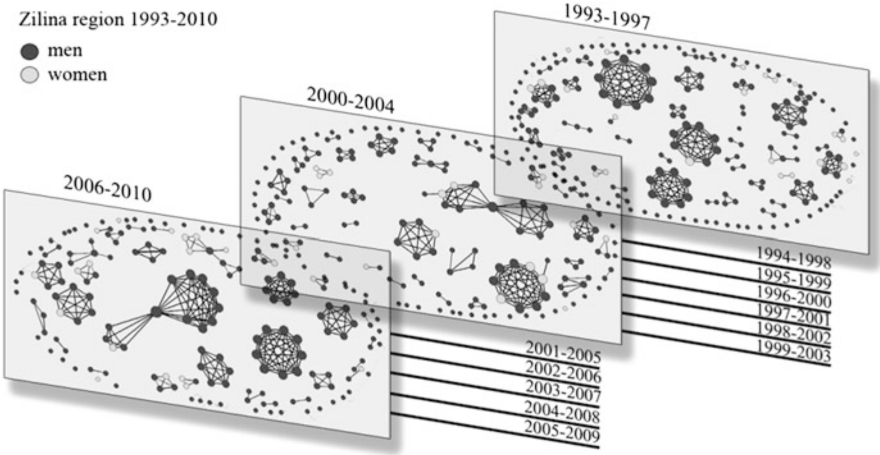

Fig. 5 Networks of inventors in Žilina region 1993–2010. Source: own

disruption of previous cross-border innovation networks. Vanishing of innovation linkages with institutions from the Czech Republic is reflected in networks primarily in the period 1992–1996, when approximately 15% of the former inventors with more than 5 connections were completely disconnected from the Slovak main network component.

A heritage of the socialistic system and following path dependence exist in the separated science, education and business components and a more comfortable focus on fundamental research. Separated roles of the knowledge sectors established by the former central planning are firmly preserved and cause communication gaps.

A well working triple helix system of industry-university-government relationships could be a driver of innovation performance. However, the relations of the triple helix institutions in Slovak regions are rather formal, non-productive and inefficient, with the exception of the Žilina region.

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