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International collaboration and spatial dynamics of US patenting in Central and Eastern European countries 1981-2010

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PRELIMINARY DRAFT; PLEASE, DO NOT QUOTE!

Abstract

How do major economic transitions and the parallel rise regarding international labor division restructure regional innovation systems? In this paper we describe the spatial dynamics of inventor activity in four of the Central and Eastern European (CEE) countries over the 1980-2010 period that covers 10 years of the late socialist period and 20 years of post-socialist transition. Our exercise uses the publicly available dataset of the United States Patent and Trademark Office (USPTO). We illustrate that CEE inventors got more and more involved in international co-operations, which resulted in a shift in the technological portfolio in CEE patenting changed after 1990 and also in better CEE patents (measured by the number of citations). Furthermore, a town-level analysis of the applicant-inventor ties also reveals the positive effects of international collaborations on innovation systems because they increase the number of towns that have at least one inventor. However, the positive effect does not last long; patenting seems to be only periodic in the majority of those towns, where inventors worked for foreign assignees only. Therefore, innovation policy in CEE countries shall foster the balance of international and domestic collaborations in order to develop their national and regional innovation systems.

Keywords: economic transition, USPTO, international collaboration, geography, inventor, patent assignee, innovation system.

JEL codes: O18, O34, P25, R11

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1. Introduction

The growing scale of international collaboration in knowledge production has been a frequently reported phenomenon since the globalization in science and patenting speeded up (Archibugi and Michie 1993; Guellec and de la Potterie 2001; Wagner *et al.* 2015). Scholars also warn us that cross-country co-operation is still weak in areas like the European Union where research integration is an explicit aim (Chessa *et al.* 2013; Picci 2010). International collaborations are important because patents produced by firms located in different countries are better (Beaudry and Schiffaeurova 2011) and also because international knowledge flows might spill over to co-located firms and inventors, which can bring dynamics to domestic innovation (Breschi and Lissoni 2001; Guan and Chen 2012; Jaffe *et al.* 1993; Varga and Schalk 2004). This latter aspect is especially important for less developed countries that can benefit from international collaborations in their knowledge production (Goldfinch *et al.* 2003; Penrose 1973; Varga and Sebestyén 2013).

However, very little is known about the effect of international collaboration on the spatial dynamics of knowledge production (e.g. the entry and exit of towns). The recent paper addresses this research niche by looking at dynamics of US patenting in towns of four Central and Eastern European (CEE) countries –Poland, Czech Republic, Slovakia, and Hungary– in the 1980-2010 period.

Our case is particularly interesting, because these countries have gone through a major economic transition from planned economy to market economy in the 1990s. Globalization gathered speed simultaneously resulting in a major challenge because foreign-owned companies and international collaboration became the dominant engine in spatial development (Enyedi 1995; Lengyel *et al.* 2015; Radosevic 2002). Although large efforts have been devoted to strengthen regional and national innovation systems in CEE after the countries joined the EU (Blazek and Uhlír 2007 Suurna and Kattel 2010), there is a common agreement that innovation policy could not cope with the above challenges due to weak local institutions and innovation links (Havas 2002; Inzelt 2004; Radosevic 2011; Radosevic and Reid 2006; von Tunzelmann and Nassehi 2004; Varblane *et al.* 2007). Thus, the adjustment of innovation policy is needed to major underlying trends in CEE patenting.

In order to illustrate these trends, we have downloaded the full set of patents filed by the United States Patent and Trademark Office (USPTO), in which at least one inventor from the CEE countries participated. USPTO data is used instead of EPO data because (1) the accession of CEE countries to the common EU market have affected the number of EPO patent applications for reasons other than inventions (Hall and Helmers 2012); and (2) USPTO patents can be expected to capture globally competitive innovation output better than EPO data (Ginarte and Park 1997, Martinez and Guellec, 2003). Data collection and cleaning are explained in detail in the following section.

We find that CEE inventors got more and more involved in international co-operations, which resulted in a shift in the technological portfolio in CEE patenting changed after 1990 and also in better CEE patents (measured by the number of citations). Furthermore, a town-level analysis of the applicant-inventor ties reveals the positive effects of international collaborations on innovation systems because they increase the number of towns that have at least one inventor. However, the positive effect does not last long; patenting seems to be only periodic in the majority of those towns, where inventors worked for foreign assignees only. Therefore, innovation policy in CEE countries shall foster the balance of international and domestic collaborations in order to develop their national and regional innovation systems.

2. Materials and Methods

2.1 Data collection

We use techniques for USPTO data collection and organization developed recently by Leydesdorff and Bornmann (2012). The database of the USPTO contains all patent data since 1790 and patents are retrievable as image files since then, and after 1976 also as full text. The HyperText Markup Language (HTML) format allows us to study patents in considerable detail (Leydesdorff 2004). One can, for example, search with names of countries, states, or city addresses in addition to the issue and/or application dates of the patents under study or classifications at the 'Advanced Search' engine of the USPTO database of granted patents at http://patft.uspto.gov/netahtml/PTO/search-adv.htm or patent applications at http://appft.uspto.gov/netahtml/PTO/search-adv.html. A set of dedicated routines download and organiz the data into a relational database that can be used for statistical analysis. These routines are open source, thus can be downloaded by the user andfurther instructions can be found at http://www.leydesdorff.net/software/patentmaps/index.htm.

In order to answer the question of the recent paper, we collected USPTO patents with at least one inventor in the Czech Republic, Poland, Slovakia, and Hungary for the 1980-2010 period using the search string 'icn/(cz OR pl OR sk OR hu) and isd/1981$$->2010$$' on August 5, 2013. The download recalled 7601 patents.

2.2 Data cleaning

Data cleaning focused on the names of the assignees and the addresses of the assignees and inventors.

Identical assignees were often recorded under multiple names, which stemmed from (1) unusual letters or typographical errors due to various language usage and (2) divergent notation of company forms (e.g. ltd and l.t.d. cannot be considered identical). Therefore, assignee names were unified by changing all the characters into capitals and removing full stops, commas, semicolons, and further typo errors like double spaces. Subsequently, divergent formats due to different language use were unified (for example when the same university was recorded in English and Polish as well in distinct patents). Finally, the data contains institutes and their sub-institutes as different assignees; these are sometimes located in a different city (e.g. the Hungarian Academy of Sciences in Budapest has its sub-institute Biological Research Centre of the Hungarian Academy of Sciences in Szeged, 170 km from Budapest). The remaining errors were incorrect fillings of the patents such as country or street names instead of the names of the cities, which could not be corrected.

As far as the addresses are concerned, the typographical errors were corrected by visualizing each city on GoggleMaps and the different formats were unified. For example, ‘Praha’, ‘Praza’ and ‘Raha’ in the Czech Republic were changed into ‘Prague’. Some of the country codes were changed during the period 1980-2010 for reasons like the dissolution of Czechoslovakia (CS) into Czech Republic (CZ) and Slovakia (SK) in 1993. In these cases country codes are only indicated as they exist currently based on the ISO 3166 standard two-digit codes at https://www.iso.org/obp/ui/#search. There were several addresses where only the country or the street name was given instead of the city names, so they were not identifiable for the map application. In these cases the headquarters of the assignees were searched on the internet by their names and countries. Inventors’ addresses were searched by their names, countries and the assignees of the patent on which they worked assuming if these parameters match, they are the same person. In many cases other patents were found on different sites where the address was correctly given in a more detailed format. The thorough cleaning enabled us to identify the location of most assignees and inventors.

Our remaining concern regarded the fact that settlements around large cities are recorded as unique towns in the data; however, inventors are likely to commute to the cities from the agglomeration. Therefore, we recoded those settlements that belonged to bigger cities’ into a ‘superior city’ category according to the following criteria. (1) Capitals, industrial and county centers have been re-coded to superior cities. (2) If a bypass route surrounds a large city, those settlements (sometimes district names, small villages or towns) which were within that route were re-coded to the superior city. (3) In the case of European locations, we used an approximately 10 km circle from the city centre for supplementing the bypass ring if there was no such route found. (4) In the case of US locations, we used a somewhat broader circle than 10 km, because more people have cars in the USA and can travel bigger distances to reach their workplace. Additionally, cities in colossal agglomerations such as New York were re-coded to the superior city even if they were remarkably further than that 10 km ring. The geo-coordinates of relevant cities have been collected by the GSP Visualizer (http://www.gpsvisualizer.com//geocoder/) and later corrected manually on GoogleMaps.

After the cleaning process the data for the 1981-2010 period includes 5078 patents from 1570 assignees and 11405 inventors from 57 countries.

3. Results

The analysis is divided into three parts. In the first step, we describe the trend of international collaboration and the share of foreign assignees in the 1981-2010 period. Then, we illustrate that the growing share of international collaboration resulted in a change of technological profile of CEE patenting. We also show that the quality of patents are better if produced in international collaboration. This is followed by a geographic investigation of assignee-inventor ties on the town level, in which we analyze the role of international collaboration on the spatial dynamics of patenting in CEE countries.

3.1 Foreign assignees and co-inventors

The share of foreign assignees indicates that innovation activity of CEE countries became dominated by international co-operations over the post-socialist transition period (Lengyel et al, 2015). We identify an assignee as foreign here if the company is from neither of the four CEE countries (the Czech Republic, Hungary, Poland and Slovakia). Accordingly, Figure 1A shows that the ratio of foreign assignees rose from slightly more than 5 percent in 1981 reaching more than 80 percent at the end of the period. The significant acceleration started in the second half of the 1980s and slowed down in the late 1990s. This may be associated with the regime change in the post socialist countries, when markets became more open and thus, working with assignees from other countries became accomplishable. However, the share of foreign assignees stayed above 70 percent from the year 1998, which supports the idea that international collaboration dominates innovation in CEE countries to a larger extent than in more developed innovation systems (Lengyel et al. 2015).

The rise of the ratio and number of foreign assignees and patents is not equally distributed among the foreign labeled countries. Collaboration aimed mostly Western European and US assignees rather than assignees from the socialist block. Figure 1B shows those countries, which had at least 80 patents related to CEE inventors during the 1981-2010 period pointing out the most important partner countries. Most of the patents were assigned by entities in the United States, but CEE inventors also worked in patents owned by German, Finish and Swedish assignees.

Assignees are counted by countries and five-year long periods in Figure 1C. Only those countries are shown that had at least 70 assignees over the full period. Slovakia does not complete the criteria, which indicates that assignees were not equally distributed among the former countries of Czechoslovakia. Though Hungary stood out in the 1980s among the CEE countries in terms of assignees, the number fell dramatically in the 1990s. The number Czech and Polish assignees also fell in the beginning of the 1990s but started to rise again from the second half of the decade and took over Hungary in the late 2000s. The difference in the trends may indicate that the innovation systems of the Czech Republic and Poland were able to overcome the challenges of the post-socialist transition, while Hungary was not.

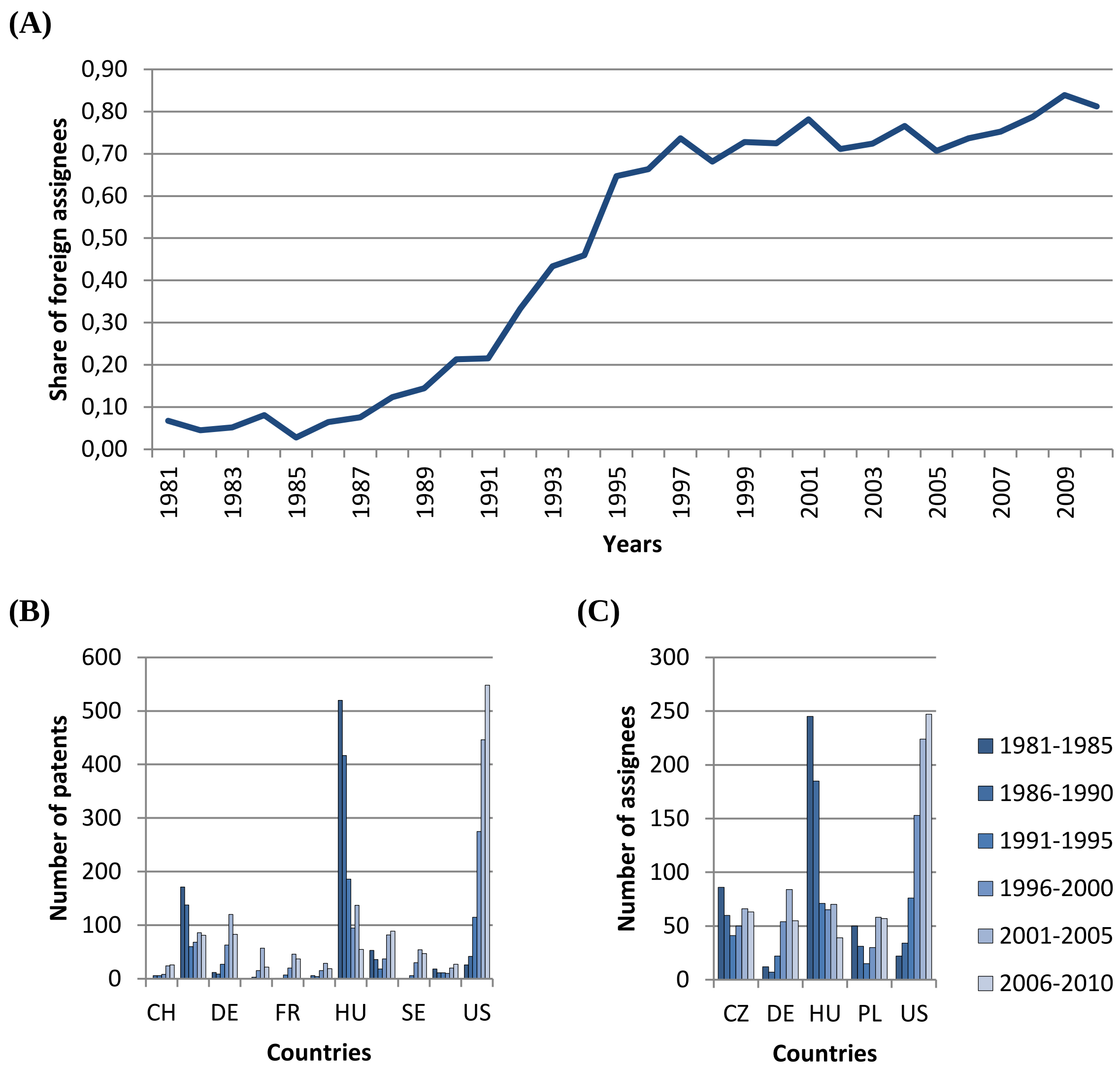


Figure 1. Share of foreign assignees and their country distribution. **(A)** Share of foreign assignees on a yearly base, 1981-2010. The number of foreign assignees was weighted by the number of patents filed by them. The result is identical when using the unweighted raw number of individual assignees. **(B)** Filed patents by countries of assignees by 5-year periods. **(C)** Assignees by countries by 5-year periods.

CEE inventors not only worked for a growing number of foreign assignees, but collaboration with foreign inventors became very important as well. Foreign inventors are those who are not from any of the four CEE countries. The ratio of foreign co-inventors grew over the 1990s, and the acceleration slowed down in the 2000 only (Figure 2A), when the ratio is almost reached 50 percent. The country distribution of foreign co-inventors working with CEE inventors also changed, which means that the share of inventors from the United States and Germany became dominant (Figure 2B). All the other important partner countries are in Western Europe (except for Canada). Interestingly, the number of inventors in from all EU member countries started to fall in the 2006-2010 period (with the exception of France); while the number of co-inventors from the US, Canada and Switzerland further grew.

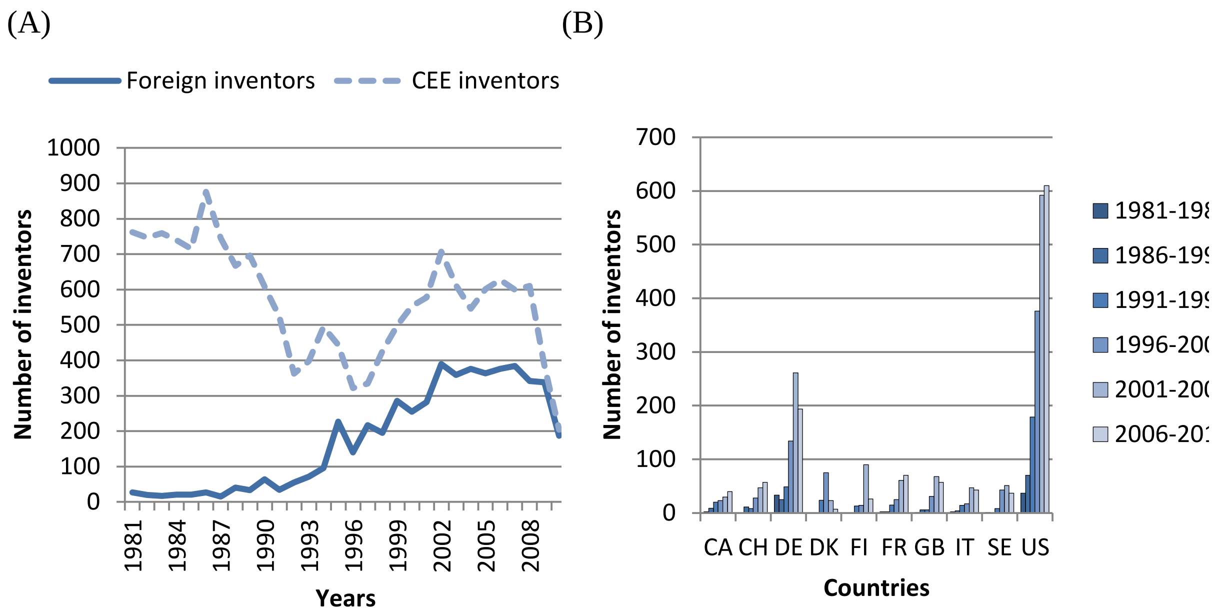


Figure 2. The number of foreign co-inventors. (A) The share of CEE- and foreign inventors weighted by the number of authored patents on a yearly base; **(B)** Foreign inventors by country, weighted by the number of patents authored by the individual inventors.

The distribution of inventors by patent and the change in the average number of inventors by patent are illustrated in Appendix 1.

3.2 The effect of international collaboration on technological profile and innovation quality

The examined patents are classified in the CPC (Competitive Patent Classification) system which is the harmonized classification system based on the existing former classifications of ECLA (European CLAssification) and USPS (United States Patent Classification). The CPC contains nine main classes from A to H[1]. Table 1 explains these main classes ranging from Human necessities to Electricity.

Figure 3A illustrates the number of patents in each class by 5-year periods. We find that Chemistry and metallurgy (C class) dominated patenting in CEE countries although this class lost from its share between 2006 and 2010. At the same time, Electricity and Physics (classes H and G) became the most important categories after year 2000. The number of patents in the other classes fluctuated during the 30 years, without any remarkable trends.

[1] The separate letter Y includes the general tagging of those patents that belong to new technological developments, cross-sectional technologies spanning over several classes of the International Patent Classification (IPC), and technical subjects covered by former USPC cross-reference art collections [XRACs] and digests(http://www.cooperativepatentclassification.org/cpcSchemeAndDefinitions/table.html). There was no patent which belonged to the Y class in the dataset.

Table 1. Fields of CPC categories

CPC	Category
A	Human necessities
B	Performing operations; transporting
C	Chemistry; metallurgy
D	Textiles; paper
E	Fixed constructions
F	Mechanical engineering; lighting; heating; weapons; blasting engines or pumps
G	Physics
H	Electricity

In a next step we find that the above shift in the technological portfolio is due to the growing dominance of international collaboration in patenting. We break the number of patents into two groups according to the location of assignees and depict these two groups in separate figures. Figure 3B illustrates the technological classes of the patents with at least one CEE inventor, which are solely assigned by companies from CEE countries. Figure 3C depicts the technological classes of patents with at least one CEE inventor, which are assigned by companies located elsewhere. The amount of patents with CEE assignees fell, while the amount of patents owned by foreign assignees rose during the period. At the beginning, foreign patents did not influence the technology classification structure of the period, but there is a growing number of patents filed by foreign assignees in Physics and Electricity, which changed the technological structure.

We use the number of citations of each patent for measuring the quality of the patents. Figure 4 illustrates the average citation of the observed patents by 5-year periods and the above CEE and foreign distinction of assignees. Naturally, the average citation falls as reaching the end of the period, since old patents had more time to be discoverd and cited than the young ones. The last period is therefore not reliable from the view of patent citation, because it is too close to the time of data collection. Regarding the location of the assignees, there is a significant differene between patents of CEE assignees and of foreign assignees, patents of foreign assignees are two times more cited on average until 2005. This suggests that international co-operation, working together with foreign assignees results scientific work of better quality.

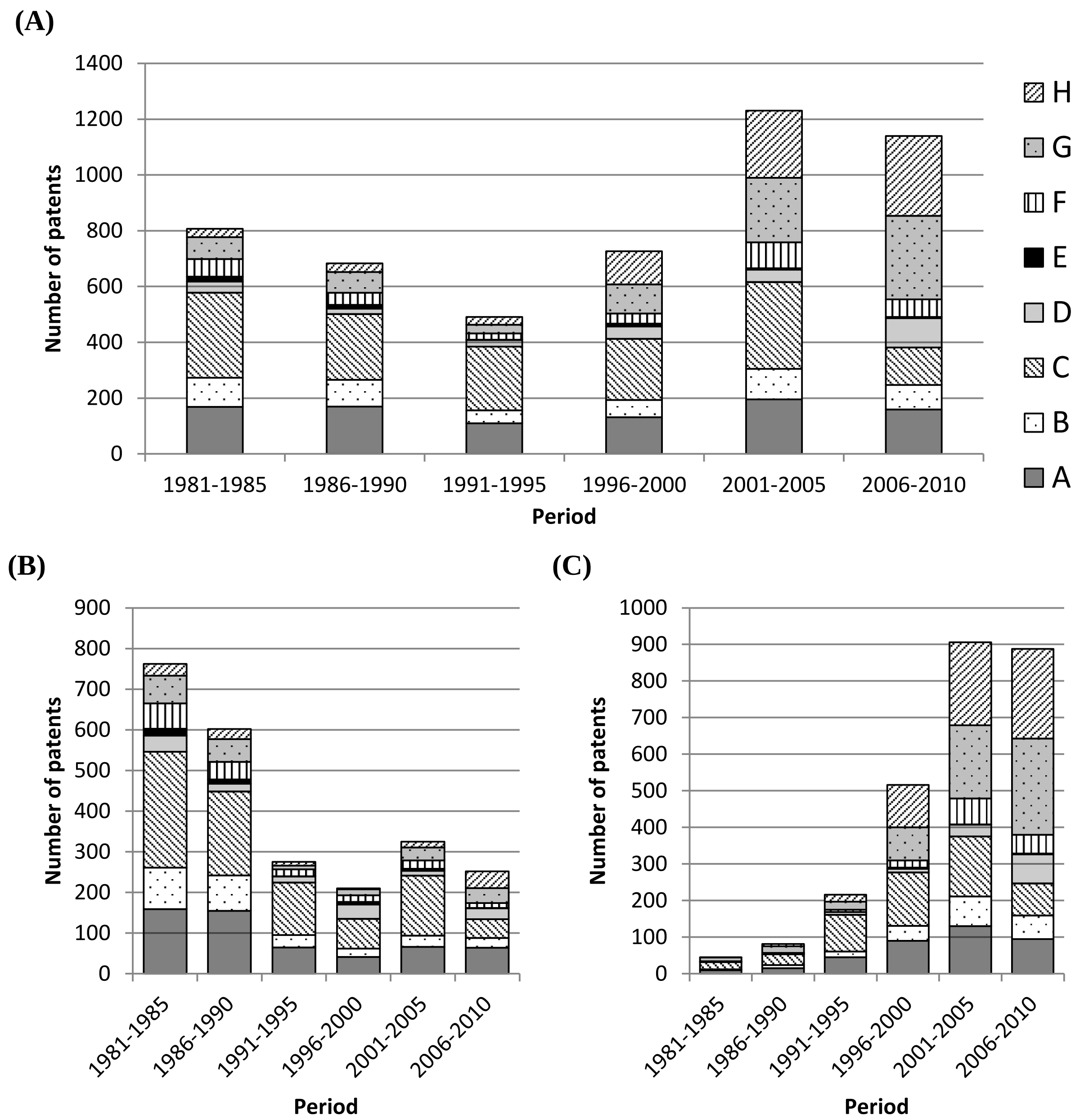


Figure 3. The number of USPTO patents with at least one CEE according to Cooperative Patent Classification by 5-year periods. (A) all patents; **(B)** patents of CEE assignees; **(C)** patents of foreign assignees.

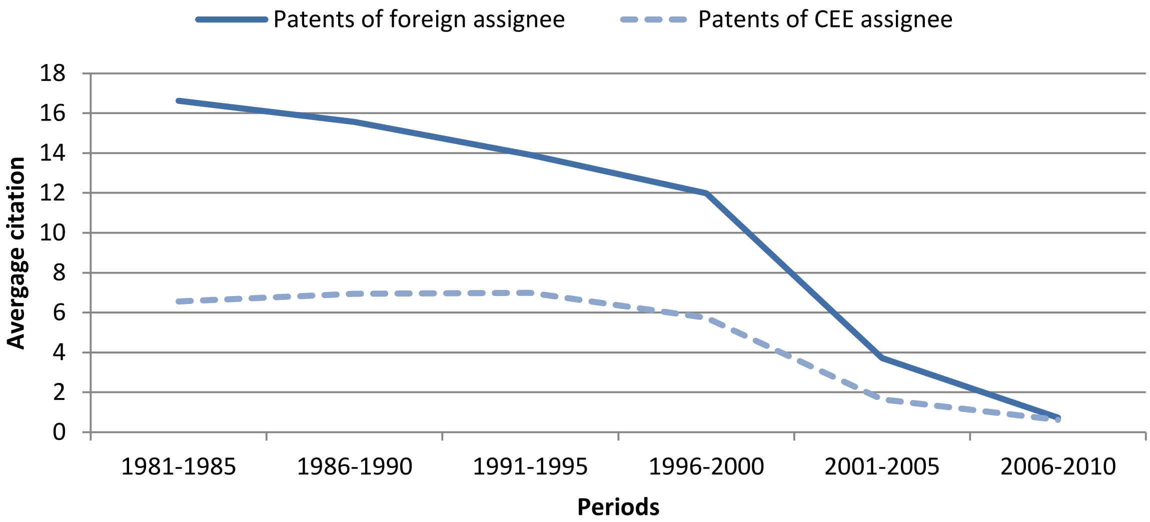


Figure 4. Average citation of patents by 5-year periods and the location of the assignee.

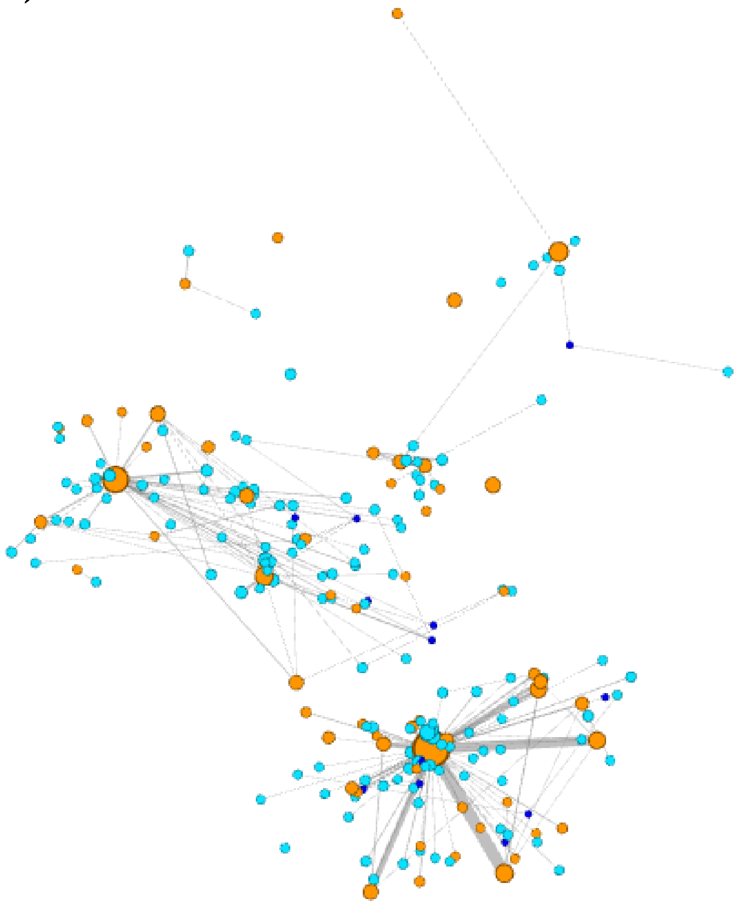
3.3 Inventor-assignees links and spatial dynamics of CEE patenting

A set of maps were drawn in order to illustrate the spatial dynamics of CEE patenting broken to six 5-years periods in Figure 5. These maps contain the CEE towns recoded as described in Section 2.2. In order to show the dynamics of assignee-inventor collaboration in space, we categorized the towns into three classes. Nodes depict those towns where (1) only inventors (light-blue), (2) only assignees (dark-blue), and (3) both inventors and assignees were located (orange) in the period. The size of the nodes indicates the number of patents filed by inventors living in the given town. Edges are defined as follows: if at least one patent was filed in a collaboration between an inventor in town A and an assignee in town B, then there is a link between towns A and B. The thickness of the edges visualizes the number of patents filed.

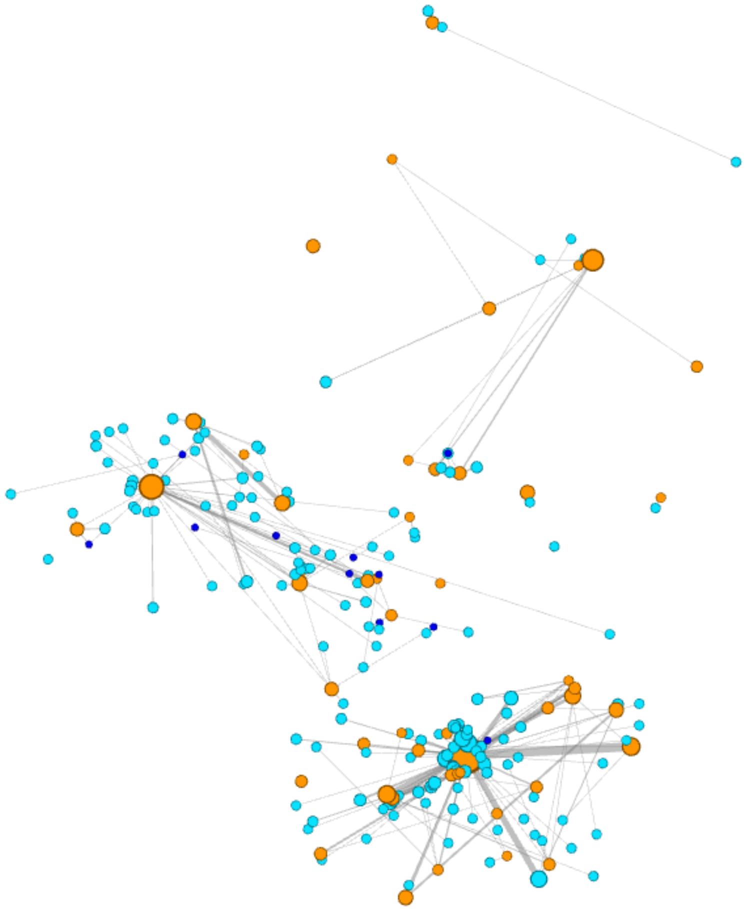
One can make few important observations when examining the maps. Not only the spatial distribution and dynamics of inventors and assignees in CEE countries but also the spatial dynamics of their collaboration can be analyzed.

Patenting seems to be concentrated in agglomerations of capital cities and regional centers like university towns. However, there is a considerable difference regarding the above statement across CEE countries, which is especially true when looking at the dynamics of light-blue nodes. Hungarian inventors are concentrated with a growing intensity in the Budapest agglomeration; while the spatial distribution of inventors in the Czech Republic became more equal over time.

(A) 1981-1985



(B) 1986-1990



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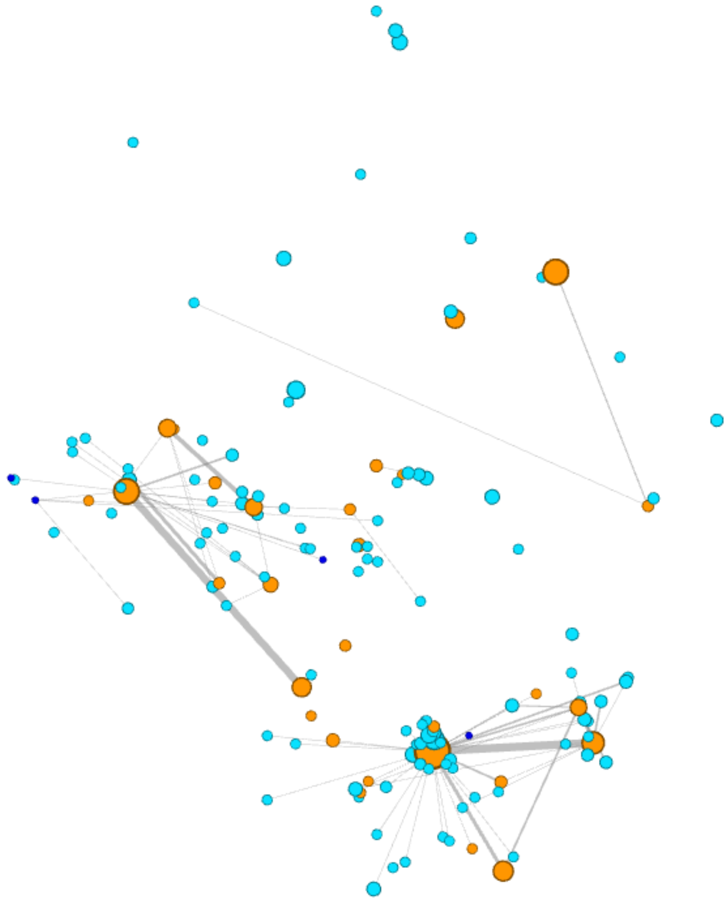
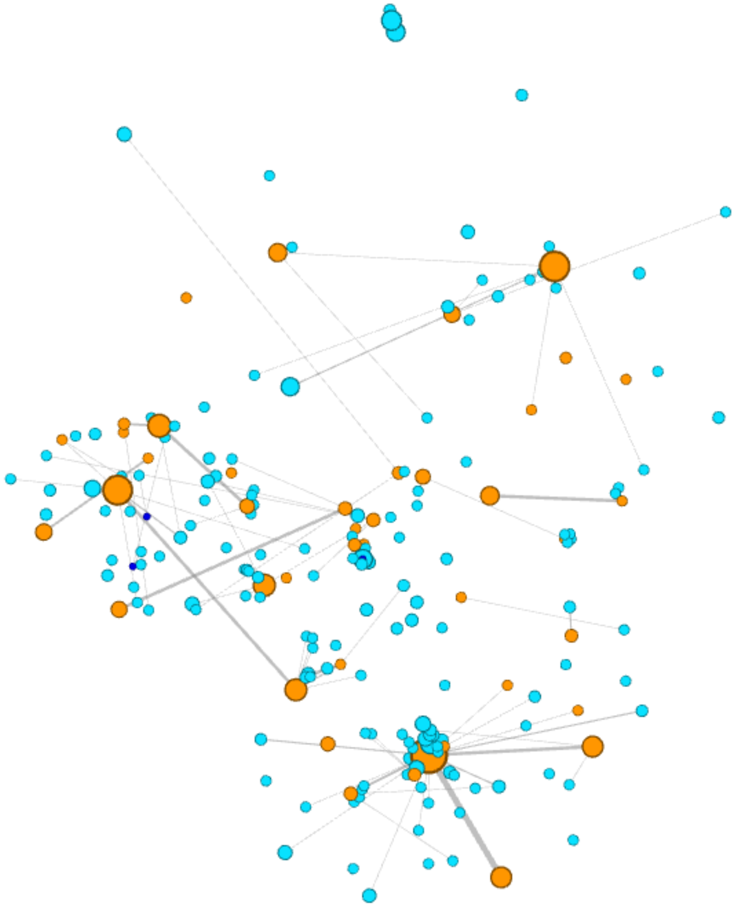
(C) 1991-1995



(D) 1996-2000



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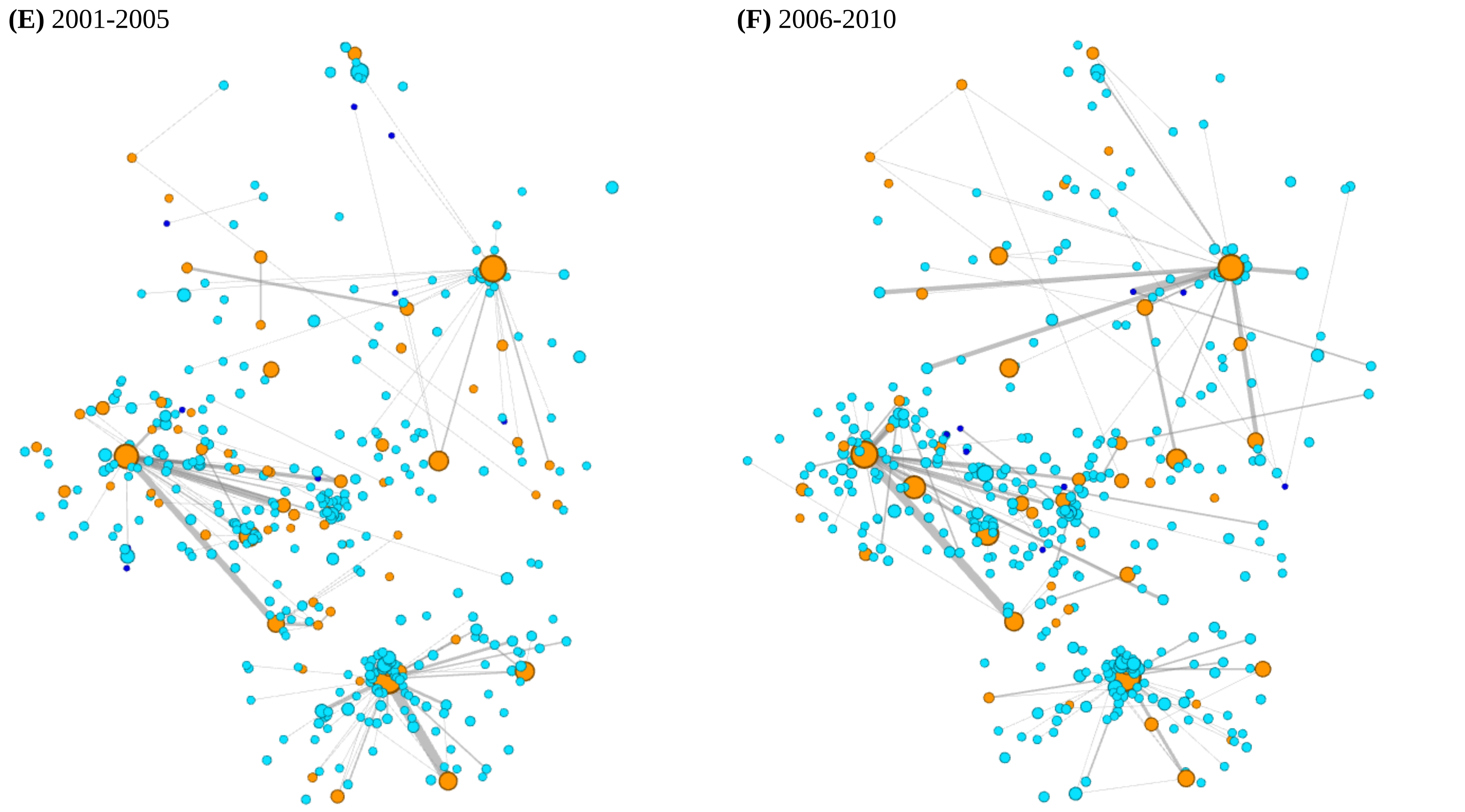

Figure 5. Assignee-inventor links between towns in CEE countries. Light-blue nodes denote towns with inventors; dark-blue nodes denote towns with assignees; orange nodes denote towns with both inventors and assignees. The size of the nodes indicates the number of patents filed by inventors living in the given town.

The maps contain many inventor towns without any connections. The inventors in these towns co-operated with assignees located in foreign countries and not in CEE. The amount of these towns monotonously grew over the full period. As we illustrated above, international collaboration intensified, in which mainly collaboration with assignees in US cities strengthened. Appendix 2 visualizes the global map of town-level collaboration in CEE patenting.

The orange nodes collected connections with some of the light-blue and also orange nodes in the CEE set; however, collaboration mostly remained within the country. The only exceptions were the collaboration between Slovakian inventors and Czech assignees before 1990. The majority of these collaborations disappeared after the cessation of Czechoslovakia despite the strong link between Prague and Bratislava.

The capital is the most important hub in the network of the Czech Republic, Poland and Hungary: the collaboration networks in these countries after 1990 became more and more star-shaped with the capital in their center. This finding is very interesting because it suggests that settlement hierarchy dominates collaboration in patenting after 1990 to a larger extent than it did in the socialist era. In Hungary, for example, the collaboration network was more complex between 1981 and 1990 than after 1990, which might be due to the disappearance of the assignees from some regional centers. Slovakia has very few towns that are active in US patenting and even less towns where assignees are located. Furthermore, Bratislava does not seem to function like the other capitals, it is not the centre of some radiuses reaching different points of the country.

Table 2 summarizes the most important indicators of the assignee-inventor town-level networks. Although the number of edges grew over the period, this is an artifact of international collaboration only. Collaboration across CEE towns became weaker, fewer collaboration ties knit towns together. The number of the towns where assignees and inventors are found as well approximately stagnated fell in the early 1990s and then rose back to the level of the 1980s. In contrast, the number of the towns with inventors increased vastly after 1995. The significant growth is true for foreign assignee cities as well, which accords evidently with the growth of foreign-related edges.

The list of top scoring cities remains quite stable over the full period (Table 2). Budapest stands out in terms patents filed by resident inventors; then Prague or Warsaw follows in a changing order. Then, Czech regional centers (Brno and Hroznetin) took over Hungarian regional centers (Debrecen and Szeged), meanwhile other major cities (Bratislava, Cracow) also make it to the top five.

Table 2. The global network of CEE patenting.

Period	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010
Edges	277 (332)	315 (360)	279 (308)	442 (482)	809 (860)	770 (808)
Edges in CEE	242 (297)	249 (294)	111 (140)	121 (161)	195 (246)	172 (210)
Inventor towns in CEE	154	165	112	170	338	367
Assignee towns in CEE	12	11	4	3	11	11
Towns with inventors and assignees in CEE	60	50	29	44	64	64
Foreign assignee towns	25	52	98	178	237	199
Top 5 towns (based on patent number filed by inventors)	Budapest (475)	Budapest (397)	Budapest (214)	Budapest (210)	Budapest (324)	Budapest (243)
	Prague (100)	Prague (87)	Prague (59)	Prague (97)	Warsaw (141)	Prague (141)
	Warsaw (33)	Warsaw (41)	Warsaw (46)	Warsaw (76)	Prague (127)	Warsaw (96)
	Brno (26)	Dunakeszi (22)	Debrecen (29)	Liberec (29)	Brno (55)	Hroznetin (60)
	Szeged (26)	Debrecen (21)	Dunakeszi (20)	Bratislava (25)	Cracow (47)	Brno (56)

Note: Edges include self-loops (when the inventor and assignee of the patent are located in the same town).

The last step in investigating spatial dynamics in CEE patenting is an entry-exit analysis on town level. We define the CEE town as ENTRY if there was no inventor in the town at *t*-1 period but there is at least one inventor at *t* period. The town is defined as INCUMBENT, if it resided at least one inventor at *t*-1 and also at *t*. Finally, the town is defined as EXIT if at least one inventor lived there at *t*-1 but no inventor at *t*. Then, we also categorize the CEE towns into three groups according the assignee-inventors links: (1) towns with CEE links only, (2) towns with foreign links only, (3) towns with both CEE and foreign links.

Table 3 contains the probabilities of town ENTRY according to the assignee-inventor link categories. The probability that inventors in a CEE town start to file US patents solely by working for assignees in another CEE towns was high in the 1980s and the 1990s as well. However, town entry was due to international collaborations with a higher probability in the 2000s.

Table 3. The probability of town entry by the type of international collaboration.

Period	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010
ENTRY at *t*	**116**	**67**	**145**	**279**	**236**
P(CEE) at *t*	95%	61%	53%	36%	37%
P(Foreign) at *t*	3%	37%	42%	54%	60%
P(CEE and Foreign) at *t*	2%	1%	5%	10%	3%

Table 4. The probability of town exit by the location of assignees.

Period	1981-1985	1985-1990	1991-1995	1996-2000	2001-2005
CEE at *t*	**199**	**191**	**80**	**101**	**129**
P(INCUMBENT) at *t*+1	43.2%	30.4%	37.5%	47.5%	37.2%
P(EXIT) at *t*+1	56.8%	69.6%	62.5%	52.5%	62.8%
FOREIGN at *t*	**5**	**6**	**37**	**74**	**202**
P(INCUMBENT) at *t*+1	60%	16.7%	48.6%	54.1%	36.6%
P(EXIT) at *t*+1	40%	83.3%	51.4%	45.9%	63.4%
CEE and FOREIGN at *t*	**10**	**18**	**24**	**39**	**71**
P(INCUMBENT) at *t*+1	100%	83.3%	87.5%	89.7%	80.3%
P(EXIT) at *t*+1	0%	16.7%	12.5%	10.3%	19.7%

One can also look at the probability of being incumbent or exit according to the type of assignee-inventor ties and for every period (Table 4). These percentage values refer to the share of those towns at *t* that maintain (incumbent) or loose (exit) the innovation activity at *t*+1.

The above probabilities suggest that the effect of international collaboration on spatial dynamics of USPTO patenting is only periodic. For instance, the likelihood of towns' disappearance from 2001-2005 to 2006-2010 does not differ concerning the two types of collaborations. However, those towns had a stable position over the full period, where the inventors worked both for CEE and foreign assignees. Therefore, CEE links are still very important for maintaining innovation.

Despite the growing importance of international collaboration in patenting, local ties might have an important role in stabilizing innovation systems.

4. Conclusions

In this paper, we used a publicly available USPTO dataset to investigate the spatial dynamics of patenting in four CEE countries (Poland, the Czech Republic, Slovakia, and Hungary) over the 1981-2010 period on the town level. This era is particularly interesting to investigate the transformation of the innovation systems in these countries, because all of them went through a transition from planned into market economy in the early 1990s.

We have shown that the share of CEE inventors who worked in international collaborations have increased monotonously over time. This trend resulted in a shift regarding the technological classification of patents and better patents have been produced in terms of the number of citations. International collaborations have had a positive effect of spatial dynamics as well, because more and more towns have entered the arena of patenting by those inventors who worked for foreign assignees. However, the spatial effect of international collaborations doesn't seem to last long; innovation is not automatically maintained in the towns after working for a foreign company. CEE collaborations are still important in order to stabilize innovation performance in towns and regions. Therefore, the balance between international collaboration and domestic co-operation shall be an important aim of national and regional innovation policies in CEE countries.

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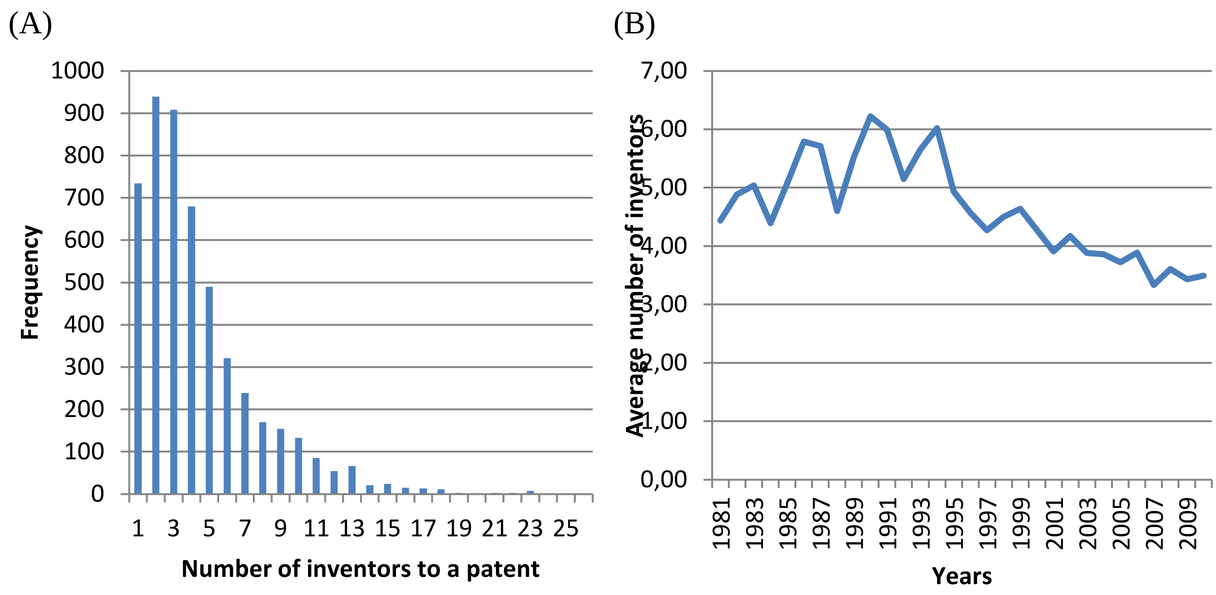
Appendix 1.



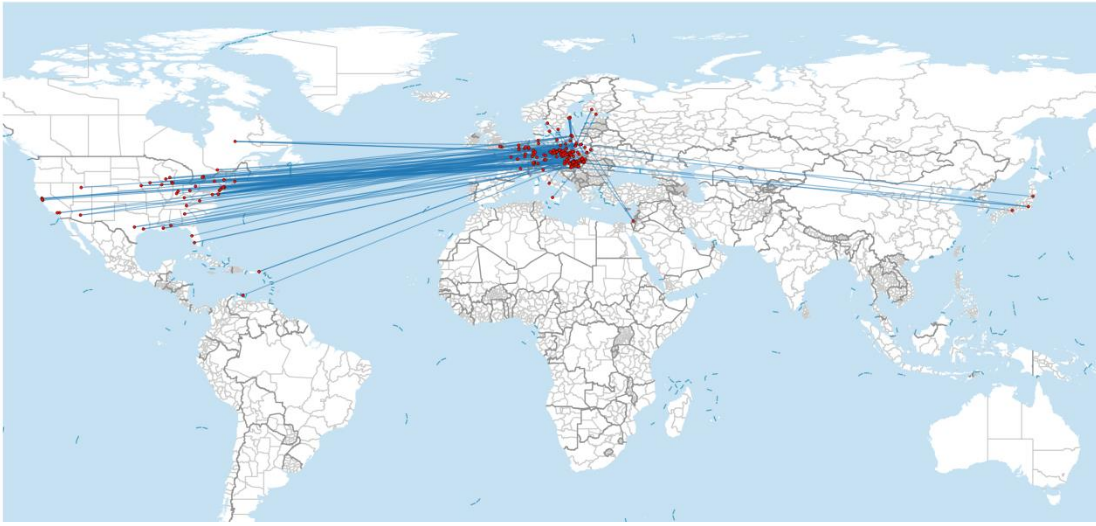
Appendix 1 Figure. Inventors to a patent. (A) Distribution of inventors to a patent over the full period of investigation. **(B)** Average number of inventors to a patent by years.

Appendix 2.

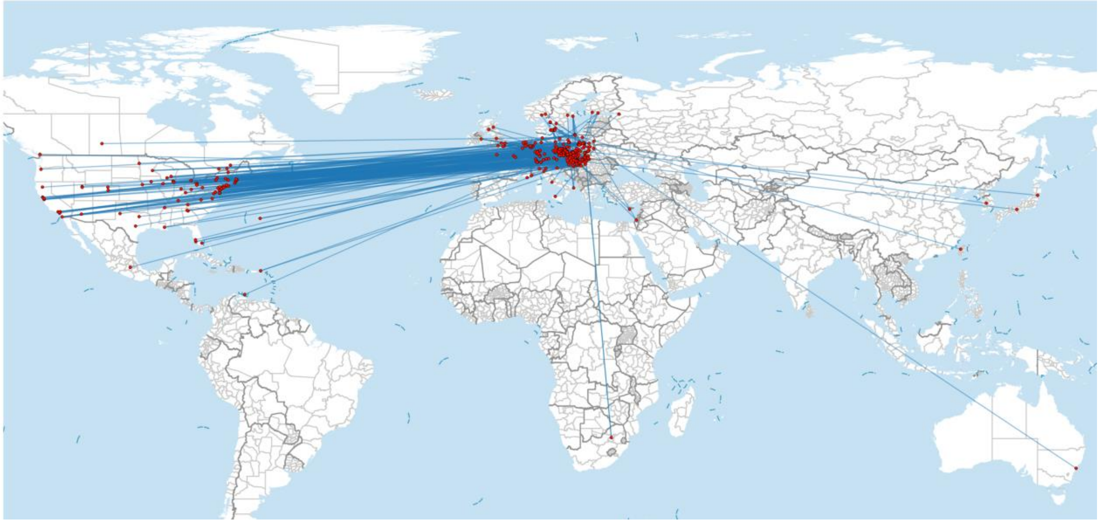
1981-1985

1986-1990

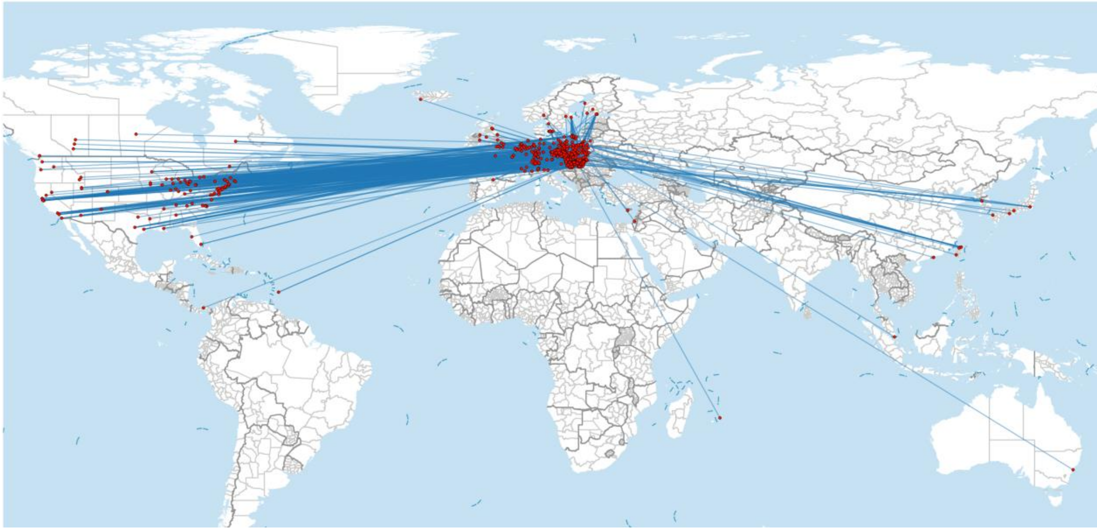
1991-1995



1995-2000



2001-2005



2006-2010

Appendix 2 Figure. The global map of collaboration in USPTO patenting of CEE countries 1981-2010.