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Slavomir Ondos, Edward Bergman

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Emerging Knowledge Networks: EU-ENC Patent Citation Links

Slavomir Ondos*, Edward Bergman^ [1]

Abstract

Do patent citations in European Neighboring Countries (ENCs) constitute elemental links in knowledge networks that provide access to sources of innovation in EU15 and EU12 countries? We use OECD patent citation data to trace the implicit networks that originate in several categories of ENCs to the principal citation communities in the EU and to other ENC countries. ENCs are found to establish fewer and fewer links with patent knowledge bases everywhere in the last 3 decades--except for EU12 countries--and the latter linkages were gained very slowly from a small base.

Patent citation links were, however, being rapidly established with advanced centers of patenting and innovation. This network topology was first explored in search for scale-free property, the power-law behavior of degree distribution indicating possible similarity with the Barabási-Albert model. Second, the evolution of a growing spatial network is focused in search for a mechanism of interplay between preferential attachment, technological and spatial structure.

Keywords

Patent citations, European Neighbouring Countries (ENCs), European Neighbourhood Policy (ENP), evolving networks, OECD Patent Data

JEL Classification

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[1] *Comenius University, Bratislava, (slavomir.ondos@gmail.com);
^Vienna University of Economics and Business, (edward.bergman@gmail.com)

Introduction

A significant element of the EC's intention in pursuing a robust European Neighbourhood Policy is to raise the standards and capabilities of neighboring states as active regional partners. EU countries have a strong interest in promoting stable borders, seeing neighbours increasingly prosper, enjoying expanded trading opportunities, engaging in broader intellectual exchanges, pursuing enhanced knowledge-intensive investment possibilities and supporting a modern orientation on the part of European Neighbouring Countries.

While such improvements may arise from widely divergent initiatives in many possible spheres of action, recent evidence in EU-15 and in several accession countries points to the primacy of knowledge flows and innovative advances in stimulating many such improvements. However, recent research has highlighted important limitations to relying on innovative knowledge flows from FDI or the surprising incapacities to capitalize upon such flows (Goldberg, Branstetter, Goddard, Kuriakose, 2008). Their research finds that unlike EU-accession countries, post-socialist *Eurasian* countries patent and innovate less than expected, gain little—sometimes even lose—innovative capacities from the presence of potential FDI-based knowledge sources, while efforts to learn by exporting has had widely varying impacts on absorptive capacities and innovative upgrading of neighboring countries. More specifically, they note (p. 32) that:

> …seven countries—the Czech Republic, Estonia, Hungary, Poland, the Slovak Republic, Slovenia, as well as Turkey—started off by participating in network trade in clothing…However, prompted by rising wages, these countries were able to move into sectors such as automotive and information technology (IT)—which are intensive in skilled labor and capital and, in the case of IT, intensive in knowledge as well—by using foreign capital and know-how and the so-called "producer-driven" production chains….Such a transition to producer-driven networks has, however, not taken place for CIS countries such as the Kyrgyz Republic, Moldova, and Turkmenistan, which are involved in the buyer-driven production chains of the clothing trade. Nor has it happened in Belarus, Russia and Ukraine…

The many facets of FDI, trade, regulatory reform and skill upgrading that are linked to the successful acquisition and absorption of knowledge flows may be found in a sampling of literatures (see as examples: Alam, Anos Casero, Khan, Udomsaph, 2008; Bell, 1997; Bell, Pavitt, 1993; Campos, Coricelli, 2002; Cohen, Levinthal, 1989; Crafts, Kaiser, 2004; Falcetti, Lysenko, Sanfei, 2006; Goldberg, Branstetter, Goddard, Kuriakose, 2008; Goldberg, Branstetter, Goddard, Kuriakose, 2010; Kravtsovaa, Radosevic, 2012) and is investigated further in several companion SEARCH working papers. With this caveat in mind, we focus on the process of knowledge flows affecting ENC neighbors.

We are interested here in the possible ENP policy effects on knowledge flows between the EU and its adjacent Neighbors to the east and south. As documented elsewhere at considerable lengths (DeBresson, Amesse 1991; Freeman, 1991; Gulati, 1998; Jaffe, Trajtenberg, Fogarty, 2000; Jaffe, Trajtenberg, 2005; Kale, Singh, Perlmutter, 2000; Kogut, 2000; Mowery, Oxley, Silverman, 1996), a useful indicator of knowledge flows is the citation of patents awarded in one place by subsequent patent applicants in the same or other places. The well-known limitations and constraints one faces in the use of patents as a proxy for knowledge flows are simply overwhelmed by the sheer advantages of using citations to patents that are announced annually, available nearly universally, include every sector affected by innovation, form the core of intellectual-property driven sectors and economies, and that can be traced to specific places, persons and organizations. These qualities are particularly important for the ENC where local data sources concerning knowledge flows are notoriously absent, unreliable or inconsistently collected/archived.

We should now ask what evidence is there of the evolution taking place in the ENCs concerning their reliance upon, and growing participation in, the beneficial knowledge flows that result from the information embedded in patent citations? We can gain insight from the analogous post-enlargement situation experienced as the EU expanded from 15 to 27 countries, all 12 being post-socialist, beginning in the mid-1990s. While the ENP falls well short of an enlargement scenario, the basic ideas remain the same: opening the EU borders to much greater interaction along a range of policies that are intended to stimulate greater trade, movement of capital, mobility of talent and knowledge flows. In an earlier paper we illustrated the cross-border knowledge flow process in the EU accession country situation, which is structurally similar to future ENP circumstances (Ondos, Bergman, 2013).

Relying upon OECD's patent data base and network analytics, we observed over 200,000 citations to patents arose in the 1999-2008 period, about 48% occurring in the first 5 years and 52% in the second 5 year period (an increase of about 7%), of which 10,500 patent citations crossed the East-West border and grew more rapidly (23%) between the periods. Three distinct communities of reciprocal patent citation observed in Europe also evolved over time, eventually to include patent applicants from accession countries, particularly their advantageously favored regions and those closest to borders. These are also the places most likely to cite patents in different patent classes as novel circumstances generated new innovations. Developing ENC regions are expected to be citation-knowledge consumers in early rounds, similar to accession country experience, a dependence which may continue indefinitely for all but the most advanced or technically-specialized ENC regions, although more standardized industrial process and business practice technologies could benefit ENC border regions initially from physical proximity. Cross-border agents may be better positioned to take advantage of new innovative possibilities by more easily absorbing cross-patent class knowledge flows suited to novel commercial exploitation.

However, post-accession EU countries remain qualitatively different than their immediate ENC neighbors due to many historical and cultural factors that are known to affect the transmission, absorption and exploitation of knowledge. Because the post-accession experience differs from their nearest neighbors in such important and subtle ways, we will attempt here to gain further insights by examining the patent citation practices of firms, organizations and individuals in EU and ENC countries, although patents in the latter countries are not invariably registered in the EPO or covered by OECD compilations, particularly those patent technologies most suited to existing indigenous sectors and resources.

Research Design

As the focus of this paper is on the evolving patterns of patent citations and associated knowledge flows that inform ENC firms and inventors, we will want to carefully distinguish both the sources of such citations and the culturally-distinct East vs. South segments of the ENC. Citations from EU-15 countries, EU-12 countries, from ENCs, and from Japan and North America are further distinguished to clarify the sources of influence on ENC development. Citations are considered "relational" to the extent that if a new patent cites an earlier one, knowledge flows from the earlier to the new citing patent "uni-directionally", i.e. the cited patent is the passive object of the knowledge relation, while the citing patent is the active "subject" of that relation.

Patents are divided into the 8 least-detailed general IPC technology classes to assess broadly emerging transitions that support subsequent transitions from some technology-dependent sectors to others. The classes and their abbreviations are: (A) human necessities, (B) performing operations and transporting, (C) chemistry and metallurgy, (D) textiles and paper, (E) fixed constructions, (F) mechanical engineering, lighting, heating, weapons and blasting, (G) physics, (H) electricity.

We intend to exploit the full population of patents available in OECD patent file since 1980, which provides 32 annual observations by cited and citing locations and technology, which are available at quite fine levels of detail.[2] Annual observations are essential to understand the underlying dynamics of technological and sectoral evolution.

Patent records include more than one "agent" of relevance to knowledge flows. The patent applicant attempts to protect the intellectual property embedded in a discovery so that its unique value can be exploited as a protected product, service or sale of the IP value to an "assignee". Therefore, the relation traced by a patent citation is clearly *commercial and uni-directional* in nature, i.e. highly-specialized knowledge flows from cited to citing patent applicant.

A second agent is/are the inventor(s) listed on the patent. In some cases such as Sweden and Italy, where the "professor's privilege" is still honored, the inventor can also be the applicant, although most applicants elsewhere, following Bayh-Dole organizational priority of patent rights, have been corporate or institutional sponsors of research. In the latter case, the inventor is typically an employee or sub-contracted entity who retains few or no IP rights: *this type of link is therefore contractual* in nature. Even so, there are knowledge flows that observe contractual relations; employers expect to receive highly secret knowledge flows from contracted employees, while employees have access to the institution's proprietary knowledge base, which results in a *bi-directional* flow of secure knowledge.

[2] Ideally, researchers could also make good use of a classification of patent applicants that would distinguish changes over time in patent citing among types of applicant, which could be individuals, firms (state or private)/ (multinational or local), universities, research institutes (state or corporate), etc., although such a classification is unavailable in standard databases. Equally problematic is the inconsistent documentation of subsequent transfer of patent rights from applicant to "assignee".

Multiple inventors on the same patent also share the *co-inventor relationship*, which implies yet another set of bi-directional knowledge flows generated by each patent, often tacit and intentionally supportive of the specific findings to be patent-protected. These are similar in origin to co-authorship links found among authors of books and published articles. An extension of this logic might also apply to the potential relation between inventors of citing patents and inventors of cited patents, although such relations would be extremely general, non-proprietary and usually considered in standard network analytics as one-degree distant.

These distinct links and flows take on particular relevance when varied locations of several agents imply a knowledge flow between their residential locations (see Maggioni and Uberti, 2011 for a useful discussion of networks vs. geographies). Accordingly, in cases where (a) citing ↔ cited patent, (b) applicant ↔ inventor, and (c) co-inventors residing in different locations (cities, regions, countries, etc.), several possible types of knowledge will have flowed between distinct places during a patent application.

A companion paper in this project (Usai, Dettori, and Gagliardini, 2013) provides a broad view of these three types of networked patent links between agents in the same geographical segments outlined above. In this version of the paper, we focus exclusively on the combination of commercial and contractual links embedded in patent applications, although we intend to experiment further with single- and multiple-link combinations.

The findings presented below are essentially descriptive, although a patent-citation estimation model is envisioned. We begin with a macro view of the principal patent generators (EU, North America, Japan) and the evolving reliance of various ENC segments on these sources. Moving down to the Eurasian theater, we focus more specifically upon citing and cited links of ENC countries and EU15/EU12 countries, for which the European Neighborhood Policy is being formulated. We are quite interested in the cross-citing dynamics of these three important continental-regions to detect emerging relations and dependencies. This is followed by a sectoral decomposition of inter- and intra-regional citation links to detect within vs. across sectoral citations and tendencies for the reorientation of ENC industrial sectors and technologies.

Macro-Level Patent Citation Links

To position our analysis in the global arena, we begin by illustrating the bi-directional citation links between specific countries that comprise our ENC region of interest, plus neighbouring EU regions, North America and Japan, two of the leading patenting regimes, to represent the other principal sources of patented innovations. As shown in Figures 1.-5., North America is depicted in the upper left corner and Japan in the lower right corner. The EU-15 countries are arrayed in a circle, flanked by two crescent halos: the inner crescent consists of EU12 accession countries and the outer crescent consists of the ENP countries, which divide between the Eurasian and North African members at Syria (SY)[3]. Each country's position is indicated by a circle of 8 points, each of which corresponds to an IPC sector[4], such that inter-country links are also IPC sector

[3] Country abbreviations: from http://www.worldatlas.com/aatlas/ctycodes.htm

[4] Sector order, starting at 12 o'clock: A.

links. The relative number of links connecting all other countries to a specific country's IPC sector is proxied by the size of its "dot" (red).

Insert Figures 1. to 3.

In 1989, our base year, EU15 patent links were concentrated on North America, Japan and Israel (Figure 1.), although Hungary and Poland had already established numerous links with EU15 countries and North America by that momentous year. By 2003, many additional links in the EU12 accompanied their accession (Figure 2.), particularly the Czech Republic and Slovakia, but also among the Balkan states. In the ENC, Egypt had linked to North America more clearly and Israel deepened linkages with North America and several EU15 countries. Very few links between ENC and EU12 countries were recorded. By 2012, links between EU12 and EU15 countries had surged (Figure 3.), as had Israel's links with many EU15 countries. For the most part, other ENC countries had very few patent links with the primary patent generators and fewer still among their ENC neighbours.

From these few snapshots, it appears that countries with multiple citation links in early periods continued to add them more rapidly than countries that lacked early links. The tendency of leaders or first-movers to gain further position is well-known in several literatures as the "Matthew Effect", "first-mover effect", "circular/cumulative advantage" and in network literatures as "preferential attachment". In other words, countries that are already well-embedded in patent networks are preferred by other countries seeking beneficial knowledge links. We can test this proposition with a simple model of preferential attachment. Links inward (indegree) and outward (outdegree) can be estimated by the following panel regression model of changing cumulative prior links (degree dynamics) over 32 time periods (1980-2012).

	Indegree		Outdegree	
	Pooled	FE	Pooled	FE
Cumulative degree	0.179 (0.000)	0.119 (0.000)	0.170 (0.000)	0.103 (0.000)
Intercept	0.015 (0.001)	-	0.016 (0.000)	-
σ^2	0.152	0.129	0.164	0.142
R^2	0.278	0.389	0.241	0.343
LogL	-5,734.4	-4,731.9	-6,199.6	-5,330.2
LM spatial lag	159.2 (0.000)	74.0 (0.000)	177.6 (0.000)	78.3 (0.000)
robust LM spatial lag	11.6 (0.001)	53.1 (0.000)	0.1 (0.726)	120.1 (0.000)
LM spatial error	269.8 (0.000)	55.5 (0.000)	217.9 (0.000)	54.2 (0.000)
robust LM spatial error	122.2 (0.000)	34.7 (0.006)	40.4 (0.000)	96.0 (0.000)

LR-tests for joint significance of cross-section fixed effects 1,317.4 (0.000) and time fixed effects 609.5 (0.000) suggests that the FE model is preferred to pooled indegree model. Same implication appears in case of outdegree model 1,149.9 (0.000), and 542.1 (0.000).

The panel regression model focuses on the relationship between cumulative degree of a network node and degree change in subsequent year. Annual steps are used. Change can only be non-negative as the citation network cannot remove previous links. Once a link is added to the network it stays there permanently. The sample consists of 47 countries (North America and Japan excluded) and 8 IPC classes (376 cross-section units of analysis).

Finding a positive significant effect of cumulative indegree on indegree dynamics supports the hypothesis that the network is evolving according to the principle of preferential attachment, as described in current physics literature (Barabasi, Albert, 1999, and further model generalizations in Jeong, Néda, Barabási, 2003; Wang, Yu, Yu, 2008; Eom, Fortunato, 2011). Previously connected nodes are preferred by new nodes entering the network as time passes. We test for the strength and significance of this effect for both outdegree (citing) and indegree (being cited). All degree change and cumulative degree variables enter the model as log-values to bring their distribution closer to normal.

Simple pooled model OLS-estimates show a significant positive effect. But the LR tests for joint significance of fixed effects, one per year and one per country-specific IPC class, show that these should be included in the model. This finding is in agreement with the Barabási-Albert model generalizations using fitness of a node in an evolving framework. In addition to cumulative degree effects, attachment of new links is also driven by time-independent relative attractiveness of each node. Time fixed effects reflect how network growth accelerates over time for specific years. After including fixed effects of both kinds, we find the effect of cumulative degree is still positively significant.

Mezzo-level Patent Citation Links

We now focus a bit more on the ENC-centered geography of patent citations and links in an effort to understand how well-integrated recent EU12 countries and ENC countries are in the global and European patenting regimes. In particular, we are interested in whether accession has accelerated EU12 citation links and whether or in which ways ENC citation links have changed over three decades.
If we wish to understand who is citing whom, it is necessary to separate the outgoing citations from the incoming, which were visualized jointly in Figures 1. to 3. Therefore, a companion set of Tables 1. to 3. was created to indicate in numbers and percentages specifically which country group (1) EU15 + EFTA, (2) EU12 + Croatia[5], (3) ENC (4) NA/JP is citing from which country group. We eliminate self- and cross-citings among EU15, North America and Japan in these tables to focus exclusively on ENC and EU12 country experience.

Insert Tables 1. to 3.

The 1989 base year (Table 1.) shows 1,220 patent links among the country groups described above, where the EU15 is cited most frequently, followed by the ENC (wholly dominated by Israel), EU12 and NA/JP. Quite clearly, ENC is the second most-frequently citation linked region due to Israel's inclusion among the ENCs.

In that same table, we see the EU15 citation links of EU12/ENC patents (168+208) in 1989 were about 90% of the reverse citation direction (194+224 EU12/ENC citation links of EU15 patents). By 2003, the percentage had risen slightly to 91% (Table 2.) and by 2012 it was 94% (Table 3.).

[5] Croatia is taken as a part of EU12 region anywhere in the text.

This indicates that EU15 country patents were increasing being linked with more places: Israel, EU12 and other ENC countries. A similar pattern arose with respect to EU12/ENC and NA/JP links: in 1989 NA/JP links citing EU12/ENC country patents were about 62% of EU12/ENC citation links with NA/JP, but this had converged to about 73% by 2012. In both cases, citation links to EU12/ENC patents were rising over time, which was of course driven heavily by Israeli patenting success and the steady growth of EU12 patenting.

Insert Table 4.

A more detailed accounting of these links is available in Table 4., which provides citation linkages between relevant pairs of citing and cited regions over 32 years. We pay attention to the following pairings:

EU12 with: ENC, EU12, EU15, NA/JP
ENC with: ENC, EU12, EU15, NA/JP

Changes in citing or being cited are generally correlated for all regional pairs, which eventually arises as well for the EU12 and ENC, following the early fallow periods when ENC had not cited or been cited by EU12 regions. Citation linkages and knowledge flows grew gradually between these adjacent regions throughout the balance of the period. Before and especially following accession, EU12 citation linkages with EU15 neighbors grew rapidly and more numerous over the 32 year period, fulfilling many of the hopes for convergence between the EU and accession countries.

However, we see the reverse case for ENC citation linkages with EU15, which presents a clear challenge to the EU's expectation for a successful ENP. Citation links between the two were only half as numerous in 2012 as they were in 1980, falling steadily over the observation period! Since most citation links of the ENC originate or are destined for Israel, this reversal must be considered accordingly. Even so, a successful ENP is expected to reverse the decline in knowledge flow links between the EU27 and the ENC. The difficulty of such a reversal is highlighted by the fact that ENCs have also lost citation links with North America and Japan during this period. This is a troubling pattern, if we infer that the ENC links with global knowledge flows are not keeping pace, but are instead becoming more and more isolated from them.

Perhaps ENC regions are increasingly reliant upon regionally-appropriate knowledge (including Russian and Turkish) being generated, patented and cited internally. Indeed, we can also see progressively more *internal* link citations within EU12 countries over the three decades. If the ENC replicates the EU12 experience in general terms, we might also expect to find more internal ENC knowledge flows. But the ENC shows no increase, rather it has *lost* internal knowledge flows as self-citation linkages declined steadily over the same period. The ENP may need to be recalibrated to take full account of these potential deficiencies.

Preferential attachment tested: An exploratory model

In this paper our intention is to explore an evolving citation network between country/IPC specific patent groups localized geographically by residence of individual inventors. The setting is similar to citation networks among academic papers. The network is directed and non-weighted, strictly pointing towards past. This prevents formation of closed loops in the pattern. We also construct a cumulative network. Once a linkage appears from one specific patent group to another it remains permanently.

Our generalization, however, is that one patent that cites another can be and usually is represented by more than one IPC and sometimes more than one country if the team of inventors is international. The most simple and useful way of capturing cross border properties in a geographical and technological sense is multiple counting. We refrain from preparing a network of citation fragments here as is a usual practice in patent citation literature. Because our main interest is in evolution of the complex multidimensional network structure and not resulting intensity of citation phenomenon itself, this generalization potentially doesn't bias intended results.

A traditional way of approaching spatial interaction networks in terms of regression analysis is to separate three different phenomena affecting appearance and intensity of a representative flow. Two of them are expressions of relevant quantities or qualities at its source and destination, which may differ considerably from expressions of the many possible dimensions of distance separating them. Pooling of the flows along time provides a sufficiently dense interaction matrix to exploit in such a regression model.

The usual set of parameters from these models includes positive significant effects from scale variables in source and destination and negative significant effect of distance variables. Recently recognized practices of adjusting for spatial structure present both among flows and sets of qualities linked to interacting entities usually adds further evidence of spatial autocorrelation that generates additional indirect and network effects to the direct effects of explanatory variables.

However, these models still fail to replicate one of the crucial general features present in empirical networks. These networks are usually power law distributed. Most of the network is sparsely interconnected while a nonlinear hierarchy of relatively few hubs concentrates most links to themselves. Such network structures have no meaningful representative flow. The mean is located somewhere in an area of low network density, biased towards the high density hub-centered network components. Observed from this perspective, a network replicated from many representative, or mean flows, is therefore meaningless and can never become an accurate representation of its empirically observed counterpart.

Possible ways out of this problematic situation seems to have been explored in research areas concerning complex networks, having their roots in physics. It has been recognized that a missing piece of crucial importance for establishing empirically observed power law patterns in networks is time. An evolving network is of course not an innovative concept itself. Studying them for many decades, network scientists however remained fixed on the idea of random evolution.

Randomness in attachment of newly arriving nodes and the establishment of internal linkages among nodes already present unfortunately cannot drive a network to resemble the common scale free property observed empirically. Little has changed along these lines until Barabási and Albert revealed the role of preferential attachment in network evolution, finally opening door for a conceptually and completely new way of modeling, and in this sense also for regression analysis based on networks.

Citation linkages between academic papers that have a clear structure and temporal footprint became one of the typical real world subjects of study in this new established research. It was soon found that a non-revolutionary yet still conceptually simple preferential attachment model has low strength when facing complexities present in observed citation counts between papers published over many decades recorded in academic journals databases. Besides the effect of cumulative degree on degree dynamics, it has been found that each node has its own quality, so called fitness, in practice modifying the speed of accumulation of citations. Papers long present in academic discourse then have advantage before new papers, but their differentiation in terms of citation attractiveness can strengthen their accumulation power significantly more and also less than an average paper would.

Another feature discussed is the variation of the effect from citations accumulated in different time, with varying citation lag. The literature identifies an exponentially decreasing correlation between degree dynamics and increasingly lagged past citations present in an evolving citation network. It seems that usually only latest two to three years of citation history matter for current citation dynamic of a node.

Our model should generate a replicated cumulative citation network among country/IPC specific nodes along time as closely resembling empirical network as possible. Correct estimation of stability, changing role of each country and technological field of patenting, including role of citation lag and spatial structure, is expected to reveal important evidence of a politically induced knowledge exchange process hidden below many layers of statistical complexities necessarily present in available data on patent citations.

Knowing that countries and regions are positioned uniquely across geographical space and at varying mutual distances suggests that the citation links between them are probably not independent of such distances, but rather are mutually interdependent to some extent. The country nodes of a patent citation network are further localized at various distances in the abstract technology space along IPC sector dimensions. Therefore we must to check whether a spatial structure is present in the panel framework analyzed. First as "Small W", weight matrix considers internal technology dependencies present only in neighbouring countries (an alternative weight matrix adds dependencies in the same country, "Large W"). The IPC class in one country is assumed to be related to same IPC classes in neighboring countries. Using this assumption, LM tests and their robust versions suggest that spatial structure requires correction in the panel model in the form of both spatial lag and spatial error.

Spatial panel Durbin models allow one to test both generalizations. We include both kinds of fixed effects and spatially lagged dependent and independent variables on the right hand side of equation. Alternatively, the "Large W" version is also used, which assumes that an IPC class in a country is interdependent with all other IPC classes in the same country, as well as with all IPC classes in all neighboring countries. This is a more realistic assumption. These models are in the "Large W" columns below. Model interpretation will focus on last three lines in each column.

All values appear positive and significant. Direct effect measures the magnitude of effect from the same EU12 or ENC node. Indirect effect measures the cumulative effect from all neighboring nodes. These also affect node dynamics, as we can clearly see. The total effect then measures overall effect of cumulative degree on degree dynamics.

	Indegree		Outdegree	
	"Small W"	"Large W"	"Small W"	"Large W"
W*Dependent degree	0.107 (0.000)	0.505 (0.000)	0.105 (0.000)	0.472 (0.000)
Cumulative degree	0.102 (0.000)	0.094 (0.000)	0.075 (0.000)	0.063 (0.000)
W*Cumulative degree	0.059 (0.000)	0.028 (0.059)	0.103 (0.000)	0.083 (0.000)
σ^2	0.132	0.129	0.145	0.142
R^2	0.395	0.406	0.354	0.364
Corrected R^2	0.046	0.048	0.039	0.041
LogL	-4,679.3	-4,596.0	-5,245.3	-5,175.1
Wald test spatial lag	32.2 (0.000)	3.6 (0.059)	89.0 (0.000)	29.6 (0.000)
LR test spatial lag	33.8 (0.000)	6.7 (0.010)	92.8 (0.000)	38.3 (0.000)
Wald test spatial error	48.9 (0.000)	34.0 (0.000)	110.5 (0.000)	69.6 (0.000)
LR test spatial error	50.7 (0.000)	39.8 (0.000)	114.8 (0.000)	81.8 (0.000)
Direct effect	0.103 (0.000)	0.095 (0.000)	0.077 (0.000)	0.064 (0.000)
Indirect effect	0.076 (0.000)	0.150 (0.000)	0.122 (0.000)	0.212 (0.000)
Total effect	0.180 (0.000)	0.245 (0.000)	0.199 (0.000)	0.276 (0.000)

We can see that indirect (external) cumulative effects on citation dynamics are considerably stronger than direct (internal) cumulative links. The cumulative effects of citing (0.276) are also larger than cumulative links of being cited by others (0.245). But the results also support the assumption that linkages between IPC sectors should go beyond links with other regions to include linkages with sectors within the same region.

In other words, adding regional self-citation across IPC classes strengthens our model of preferential attachment and supports the proposition that patent knowledge of the most highly-connected countries and regions is likely to attract the most future citations. Since these are the links to EU15 and JP/NA that ENCs are steadily losing, a relevant ENP must come to grips with either the ability of ENCs to better absorb knowledge embedded in world-class patents or to somehow connect ENCs to other appropriate sources of patent (or other) knowledge suited to

ENC circumstances and conditions. Perhaps these other sources may be found in the patenting regimes of the Russian Federation or Eurasian patent offices[6].

IPC sectoral-citation patent links

The data also permit us to move beyond the country or region engaged in patent citing to consider the technological fields in which such patents are registered. Increasing self-cited patents in a single IPC may indicate the consolidation of knowledge competencies in a certain field, while self-citations across other IPCs could suggest beneficial technological innovations of the sort that propel technological clusters. Lagging regions with traditional industries may increasingly cite patents developed elsewhere that offer chances for upgrading, particularly patents in other IPCs that provide better processes or inputs. At the same time, transitional regions may rely less often on links previously developed with IPCs that are no longer relevant to ongoing modernization efforts. In short, we may find useful information embedded in the changing mix of IPCs of patents cited over time.

We begin our inquiry by examining the general patterns of IPC cross-citation in the full citation system described earlier. Tables 5., 6. and 7. are matrices of IPC class citings and cited for three periods: 1989 baseline, new links between 1990 and 2003 (EU10 accession), and 2004 to 2012. The full set of EPO citations is 10,253, of which 1,220 had accumulated from 1980 to 1989, followed by 5,036 additional between 1990 and 2003, and 3,997 additional from 2004 to 2012. This provides three snapshots of the IPC citations arising in the global system of EPO patents, across which we might observe important shifts of pattern. Judging by citation links alone, IPCs A,B&C are the largest in terms of citations, D,E&H the smallest (and fastest growing), while F&G are neither and show no distinct trend. However, if one judges high to low rank in terms of percentage growth of citation links over these time periods, D,E&H rank first, second and third fastest in growth rates, while A,B&C drop to fourth, sixth and seventh. These and further changes may be observed in a graph in Figure 4., which provides the two-period overview of citing vs. cited patents for each of the eight IPC. There is obviously considerable dynamism underlying patterns of cross-IPC citation.

Insert Tables 5. , 6., 7.

In no case are cross-IPC citations in Tables 5., 6 and 7. greater than self-IPC citations (red font), although the former are quite similar for D (textiles and paper), which could indicate other important sector sources of upgrading of these traditional technologies registered at EPO. All IPCs in the three periods do cite at least one other sector(s) (bold font) at quite high rates, which reflect technological interdependencies among technologies and industry sectors. While several shifts in cross-citation arose between the three periods, we will focus only on the most important one or two cross-citations for each IPC and comment only on those whose links changed markedly.

[6] The content and structure of these alternative patent regimes are not well known, but may deserve further attention as an alternative source of suitable technological advance for some ENC east countries.

During the 1990-2003 period, three such shifts occurred, affecting the citation patterns of “C” chemistry and metals, “E” fixed constructions, and “G” physics. In 1989, IPC “C” cited “B” (performing operations) rather heavily, which dropped nearly by half during the following period. On the other hand, citation links to “B” rose substantially from “E” during this same period. Physics (G) linked strongly with IPCs “A” and “C” in 1989, but by the 1990-2012 period, the IPC electricity (H) had exceeded “A” and “C”, both of which remained highly linked.

Three additional shifts of comparable magnitude occurred in the 2004-2012 period. The first concerns “B”, whose citations linked much less frequently with “C”. Textiles and paper (D) relied on more citation links with “A” (human necessities), while “F” (mech. engr. / light / heat) forged more citation links with “H” (electricity). These should be seen as examples of the evolving sources of patent innovation that reshaped the overall citation pattern during the course of three decades.

Insert Figure 4.

ENC patent and knowledge citation flows

We now summarize a set of similar tables for subsets of relations of interest to understand the situation of the ENC. However, the ENCs have far fewer links with others, so it is necessary to examine how the relative importance of IPCs shifts over time in terms of which sectors are citing or being cited (shifts in 1-8 rank order). In general, the most frequently citing and cited IPCs are A, B and C, while the least are D and E. Table 8. shows ENC’s relation to: (a) own patents, (b) EU12 patents and EU15 patents, with 3 subpanels for each of these regions, divided first by citing IPCs and cited IPCs, and then by period (1989, 1990-2003, 2004-2012). Panels (a) and (b) show several rank-tied IPCs, which reflect the sparseness of the data concerning self- and EU12 links; in fact, no EPO links existed between ENCs and EU12 countries in 1989.

Data sparseness may also affect the volatility of changes observed for ENC self-citations in panel (a). As ENC countries were adjusting to dramatic changes of environment, IPC sector “H” (electricity) cited more ENC patents in the second period, causing its citation rank to rise considerably and then falling back. The same conditions accompanied citation ranks for sectors “A” (human necessities) and “B” (performing operations) to drop initially, with “A” recovering its leading rank as patent citer but “B” remaining at mid-rank. Fewer shifts in rank are observed among IPC sectors cited in the ENC. “A” marked loss of citation links pushed “G” (physics) well down the rankings across the periods, while a late period rise propelled “A” to the most-cited sector at the same time it regained its rank as the ENC’s leading patent citer.

The ENCs could also cite their immediate EU12 neighbouring countries, assuming proximity may have provided the necessary familiarity, panel (b). However, proximity proved useless in the first period, as there were no ENC citations of EU12 patents registered at the EPO. By the second period, 46 citation links had been established, with “G” establishing notably more citation links by the last period, while “C” (chemistry and metals) established fewer. Cited patents changed little over the last two periods, with IPCs “A”, “B” and “C” as the top three EU12 suppliers. Total citation links between ENC and EU12 were only 98 in the last two periods, only modestly more than ENC's 67 self-citation links. Based on the evidence, ENCs cannot count heavily upon EU12 countries for important knowledge flows.

Insert Table 8.

If the ENP is to have full effects, the patent generating power of the EU15 countries will need to be drawn upon more fully by transition countries of the ENC, similar to the EU12 experience. Panel (c) of Table 7. provides additional information about these flows over three decades. ENC sectors whose rank as patent citers changed most were IPCs "G" (physics) and "A" (human necessities). The ENC physics sector rose from mid- to the second-ranked citer of EU15 patents in the 1990-2003 period—just as it had for EU12 patents in the final period—but then fell back to mid-rank in 2004-2012. Human necessities (A) rose in rank as citer of EU15 patents to first position and remained there during the last two periods, just as it had for self- and EU12 patents, which probably reflects the needed modernization of traditional consumption goods and their producers. ENC chemistry and metal sectors (C) established fewer citation links to EU15 patents by the second period, staying mid-rank through the last period, as it had for EU12 patents. When considering the EU15 patent classes cited by ENC, the only substantial change in rank was that "A" (human necessities) resumed its position as the top supplier of patents to the ENC, which was its position with regard to ENC and EU12 sources and as mentioned above, ICS "A" was the leading citer of patents everywhere.

Conclusions

The opening of European Neighbouring Countries to external influences and participation coincided with the rapid emergence of intellectual property, innovation and global engagement of economies. When 30 years of OECD patenting records for countries in the European, Eurasian and North African regions are compared, it is clear the recent accession countries have integrated quite rapidly by establishing citation links to key patenting sources, but ENC regions have not, Israel excepted, although very minor expansion of ENC patent links with EU accession countries was noted. While ENCs continue to lag behind, the most active countries have increased their contacts worldwide in the pursuit of evermore sophisticated inventions and innovations. Further work underway employing a class of Stochastic Actor-Oriented Models (SAOM) may help clarify futher the 30 year evolution of link development between ENCs and other regions, including cross-IPC class citations.

Our findings thus far imply that the primary European sources of advanced intellectual property and patenting knowledge are based upon forms of scientific sophistication that appear to far exceed the absorptive capacity of lagging ENCs to benefit from knowledge flows. The only apparent linkages are to the recently acceeded EU countries, but these are episodically few and slow to grow. Perhaps ENCs may choose to gain their most relevant innovative inputs from other neighbours (Russia, Turkey), but if the EU wishes to remain influential in the technological and sectoral development of ENCs, it may prefer to consider policies that increase ENC capacities to explore, absorb and exploit the world's patent knowledge bases.

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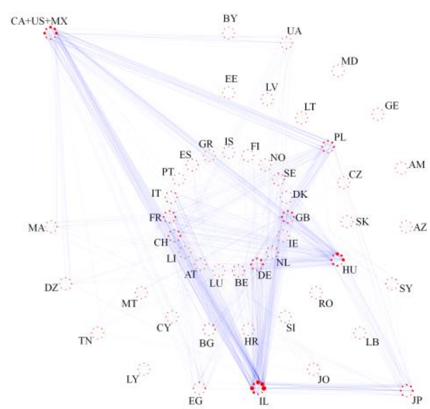


Figure 1. Cumulative binary directed patent citation network in 1989, shortly before collapse of the East European socialist regimes.

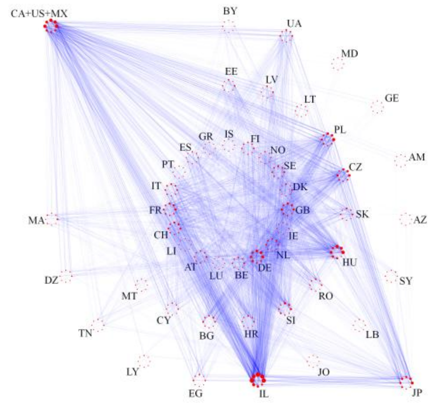


Figure 2. Cumulative binary directed patent citation network in 2003, shortly before enlargement of EU15 by 12 ENCs.

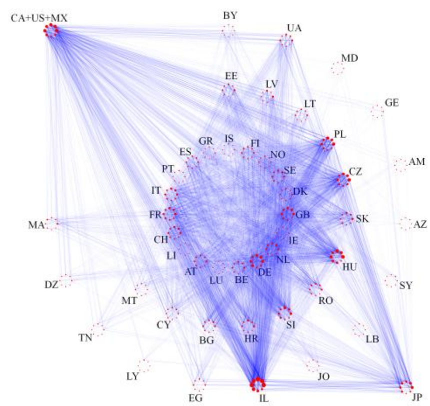


Figure 3. Cumulative binary directed patent citation network in 2012.

			Citing		
Cited	1	2	3	4	
1	-	194	224	--	418
2	168	38	0	51	257
3	208	5	26	85	324
4	-	107	114	-	221
	376	344	364	136	1,220
1	-	*15.9*	*18.4*	-	*34.3*
2	*13.8*	*3.1*	*0.0*	*4.2*	*21.1*
3	*17.0*	*0.4*	*2.1*	*7.0*	*26.6*
4	-	*8.8*	*9.3*	-	*18.1*
	30.8	*28.2*	*29.8*	*11.1*	*100.0*

Table 1. Cumulative binary directed patent citation network in 1989.

	Citing				
Cited	1	2	3	4	
1	-	1,523	731	-	2,254
2	1,326	245	46	313	1,930
3	782	81	78	256	1,197
4	-	556	319	-	875
	2,108	2,405	1,174	569	6,256
1	-	*24.3*	*11.7*	-	*36.0*
2	*21.2*	*3.9*	*0.7*	*5.0*	*30.9*
3	*12.5*	*1.3*	*1.2*	*4.1*	*19.1*
4	-	*8.9*	*5.1*	-	*14.0*
	33.7	*38.4*	*18.8*	*9.1*	*100.0*

Table 2. Cumulative binary directed patent citation network in 2003.

	Citing				
Cited	1	2	3	4	
1	-	2,839	946	-	3,785
2	2,482	525	98	494	3,599
3	1,089	161	93	363	1,706
4	-	808	355	-	1,163
	3,571	4,333	1,492	857	10,253
1	-	*27.7*	*9.2*	-	*36.9*
2	*24.2*	*5.1*	*1.0*	*4.8*	*35.1*
3	*10.6*	*1.6*	*0.9*	*3.5*	*16.6*
4	-	*7.9*	*3.5*	-	*11.3*
	34.8	*42.3*	*14.6*	*8.4*	*100.0*

Table 3. Cumulative binary directed patent citation network in 2012.

	4 → 3	3 → 4	1 → 3	3 → 1	2 → 3	3 → 2	3 → 3	4 → 2	2 → 4	2 → 2	4 → 3	3 → 4
1980	0	0	16.7	50	0	0	0	0	25	8.3	0	0
1981	11.8	9.8	21.6	23.5	0	0	3.9	3.9	9.8	2	11.8	9.8
1982	7.5	8.5	20.8	20.8	0	0	1.9	4.7	8.5	2.8	7.5	8.5
1983	7.4	8.4	17.2	24.6	0	0	3	3	5.9	2	7.4	8.4
1984	6.2	7.6	18.5	24	0	0	2.6	3.8	7	1.5	6.2	7.6
1985	6.4	13.6	17.1	21.7	0.8	0	2.3	2.7	6.6	2.1	6.4	13.6
1986	6.2	11	17.1	20.9	0.6	0	2.6	2.4	7.2	2.9	6.2	11
1987	5.9	10.5	17.4	20	0.5	0	2.1	3.3	8.4	3.1	5.9	10.5
1988	5.9	9.5	17.8	17.9	0.5	0	2.2	3	9.9	3.5	5.9	9.5
1989	7	9.3	17	18.4	0.4	0	2.1	4.2	8.8	3.1	7	9.3
1990	6.9	8.8	17.8	18.1	0.4	0	2.1	3.8	8.5	2.8	6.9	8.8
1991	6.7	8.5	17.6	18.7	0.3	0	2.1	4.2	8.2	2.7	6.7	8.5

1992	7.4	8.2	16.9	18.5	0.3	0	2	4	8.3	2.5	7.4	8.2
1993	6.8	7.9	16.6	18.8	0.6	0.1	2.2	3.8	8.8	2.4	6.8	7.9
1994	6.5	7.7	15.6	18.6	0.7	0.2	2.1	3.9	9.4	2.3	6.5	7.7
1995	6	7.4	14.5	17.8	0.9	0.2	2	3.9	9.7	3.1	6	7.4
1996	5.9	7.1	14.1	16.7	0.8	0.2	1.8	4.4	10.1	3.3	5.9	7.1
1997	5.8	6.5	13.6	16.3	0.7	0.3	1.6	4.2	10.1	3	5.8	6.5
1998	5.4	6.2	13.6	15.3	0.9	0.4	1.5	4.5	10	3.1	5.4	6.2
1999	4.9	5.9	13.2	14.4	1	0.3	1.5	4.6	9.9	3.6	4.9	5.9
2000	4.8	5.8	12.9	13.8	1	0.5	1.5	4.6	9.9	3.5	4.8	5.8
2001	4.4	5.8	12.8	13	1.2	0.5	1.5	4.7	9.5	3.5	4.4	5.8
2002	4.2	5.3	12.7	12.3	1.3	0.7	1.3	4.8	9.2	3.9	4.2	5.3
2003	4.1	5.1	12.5	11.7	1.3	0.7	1.2	5	8.9	3.9	4.1	5.1
2004	4	4.9	12	11.2	1.3	0.9	1.2	4.9	8.6	4.2	4	4.9
2005	3.9	4.7	11.8	11.2	1.3	0.9	1.1	5	8.7	4.3	3.9	4.7
2006	3.9	4.5	11.8	10.7	1.3	0.9	1.1	4.9	8.7	4.4	3.9	4.5
2007	3.9	4.2	11.5	10.4	1.4	0.9	1	5	8.5	4.7	3.9	4.2
2008	3.8	4	11.1	10.2	1.5	0.9	1	4.9	8.3	4.8	3.8	4
2009	3.7	3.8	10.8	9.9	1.6	0.9	1	4.8	8.3	4.8	3.7	3.8
2010	3.7	3.6	10.6	9.5	1.6	0.9	0.9	4.7	8	5	3.7	3.6
2011*	24.2	10.6	27.7	5.1	1.6	7.9	9.2	1.0	0.9	3.5	4.8	3.5
2012*	24.2	10.6	27.7	5.1	1.6	7.9	9.2	1.0	0.9	3.5	4.8	3.5

*Unreliable data due to short citation periods

Table 4. Cross-citation links 1980-2010 between regions 1 to 4, plus 3 internal

	Citing								
Cited	A	B	C	D	E	F	G	H	
A	70	24	60	2	3	13	30	8	210
B	25	66	54	4	10	27	24	9	219
C	63	43	91	7	8	11	29	14	266
D	7	5	7	9	-	-	3	2	33
E	7	14	6	2	21	13	5	-	68
F	13	26	13	-	9	50	6	6	123
G	27	27	35	1	5	10	56	23	184
H	8	16	23	-	-	6	25	39	117
	220	221	289	25	56	130	178	101	1,220
A	*5.7*	*2.0*	*4.9*	*0.2*	*0.2*	*1.1*	*2.5*	*0.7*	*17.2*
B	*2.0*	*5.4*	*4.4*	*0.3*	*0.8*	*2.2*	*2.0*	*0.7*	*18.0*
C	*5.2*	*3.5*	*7.5*	*0.6*	*0.7*	*0.9*	*2.4*	*1.1*	*21.8*
D	*0.6*	*0.4*	*0.6*	*0.7*	-	-	*0.2*	*0.2*	*2.7*
E	*0.6*	*1.1*	*0.5*	*0.2*	*1.7*	*1.1*	*0.4*	-	*5.6*
F	*1.1*	*2.1*	*1.1*	-	*0.7*	*4.1*	*0.5*	*0.5*	*10.1*
G	*2.2*	*2.2*	*2.9*	*0.1*	*0.4*	*0.8*	*4.6*	*1.9*	*15.1*
H	*0.7*	*1.3*	*1.9*	-	-	*0.5*	*2.0*	*3.2*	*9.6*
	18.0	*18.1*	*23.7*	*2.0*	*4.6*	*10.7*	*14.6*	*8.3*	*100.0*

Table 5. Citation links between IPC classes in 1989 network.

	Citing								
Cited	A	B	C	D	E	F	G	H	
A	340	103	249	27	16	50	120	43	948
B	97	223	138	31	48	87	105	57	786
C	251	148	301	48	29	50	120	72	1,019
D	41	31	41	65	5	13	13	8	217
E	23	37	26	5	119	27	28	10	275
F	51	84	48	8	37	138	38	47	451
G	106	105	104	17	27	43	233	136	771
H	39	55	68	16	15	44	128	204	569
	948	786	975	217	296	452	785	577	5,036
A	*6.8*	*2.0*	*4.9*	*0.5*	*0.3*	*1.0*	*2.4*	*0.9*	*18.8*
B	*1.9*	*4.4*	*2.7*	*0.6*	*1.0*	*1.7*	*2.1*	*1.1*	*15.6*
C	*5.0*	*2.9*	*6.0*	*1.0*	*0.6*	*1.0*	*2.4*	*1.4*	*20.2*
D	*0.8*	*0.6*	*0.8*	*1.3*	*0.1*	*0.3*	*0.3*	*0.2*	*4.3*
E	*0.5*	*0.7*	*0.5*	*0.1*	*2.4*	*0.5*	*0.6*	*0.2*	*5.5*
F	*1.0*	*1.7*	*1.0*	*0.2*	*0.7*	*2.7*	*0.8*	*0.9*	*9.0*
G	*2.1*	*2.1*	*2.1*	*0.3*	*0.5*	*0.9*	*4.6*	*2.7*	*15.3*
H	*0.8*	*1.1*	*1.4*	*0.3*	*0.3*	*0.9*	*2.5*	*4.1*	*11.3*
	18.8	*15.6*	*19.4*	*4.3*	*5.9*	*9.0*	*15.6*	*11.5*	*100.0*

Table 6. Citation links between IPC classes added 1990 to 2003.

	Citing								
Cited	A	B	C	D	E	F	G	H	
A	194	75	152	42	45	46	67	47	668
B	90	130	80	35	57	57	55	60	564
C	157	76	169	42	24	48	75	61	652
D	24	39	33	60	19	16	12	20	223
E	26	52	25	9	121	43	23	12	311
F	50	61	53	13	47	147	44	63	478
G	90	59	84	13	28	41	142	108	565
H	59	54	64	10	16	63	114	156	536
	690	546	660	224	357	461	532	527	3,997

A	*4.9*	*1.9*	*3.8*	*1.1*	*1.1*	*1.2*	*1.7*	*1.2*	*16.7*
B	*2.3*	*3.3*	*2.0*	*0.9*	*1.4*	*1.4*	*1.4*	*1.5*	*14.1*
C	*3.9*	*1.9*	*4.2*	*1.1*	*0.6*	*1.2*	*1.9*	*1.5*	*16.3*
D	*0.6*	*1.0*	*0.8*	*1.5*	*0.5*	*0.4*	*0.3*	*0.5*	*5.6*
E	*0.7*	*1.3*	*0.6*	*0.2*	*3.0*	*1.1*	*0.6*	*0.3*	*7.8*
F	*1.3*	*1.5*	*1.3*	*0.3*	*1.2*	*3.7*	*1.1*	*1.6*	*12.0*
G	*2.3*	*1.5*	*2.1*	*0.3*	*0.7*	*1.0*	*3.6*	*2.7*	*14.1*
H	*1.5*	*1.4*	*1.6*	*0.3*	*0.4*	*1.6*	*2.9*	*3.9*	*13.4*
	17.3	*13.7*	*16.5*	*5.6*	*8.9*	*11.5*	*13.3*	*13.2*	*100.0*

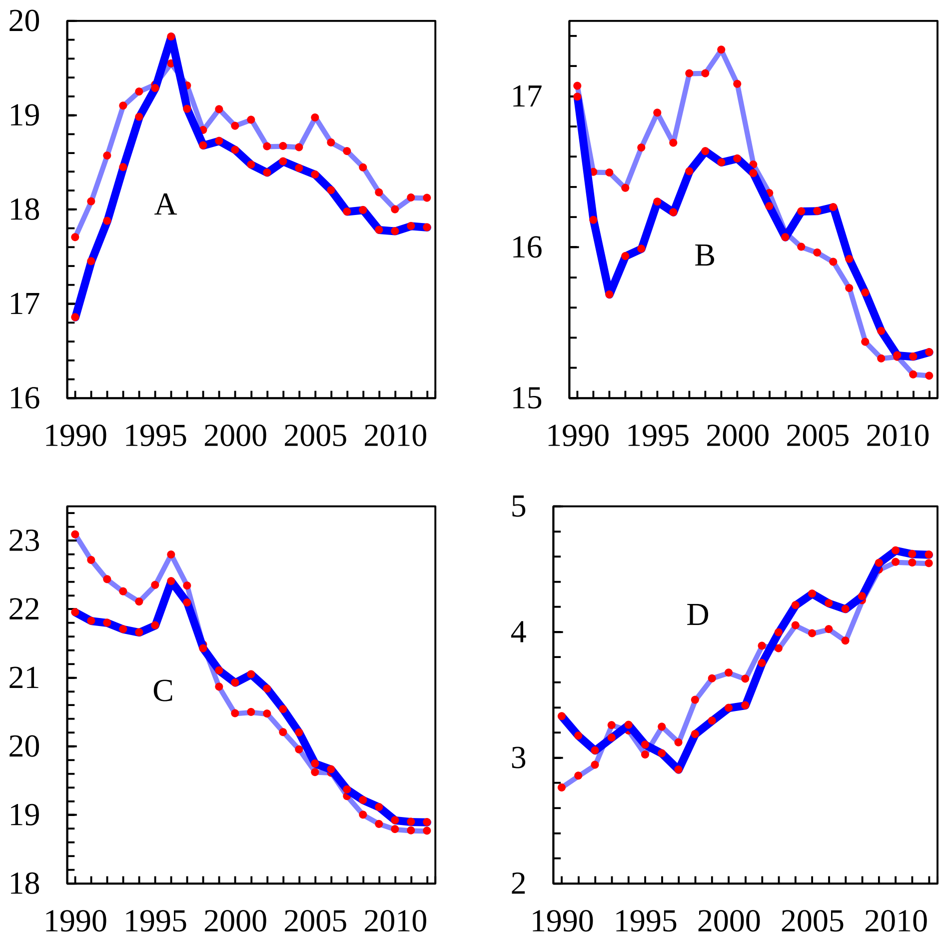
Table 7. Citation links between IPC classes added 2004 to 2012.

8-A		Subnetwork 3→3			
Citing			Cited		
(26)	(52)	(15)	(26)	(52)	(15)
1 1980-89	2 1990-03	3 2004-12	1 1980-89	2 1990-03	3 2004-12
A, B	C	A	C	C, H	A
A, B	H	C, F, G	G	C, H	C
C, F, G	A	C, F, G	A, B	A	E, F, H
C, F, G	D	C, F, G	A, B	G	E, F, H
C, F, G	B	B, F, H	F	D	E, F, H
E	F, G	B, F, H	D, E, H	B, E, F	G
H	E, G	B, F, H	D, E, H	B, E, F	-
-	E		D, E, H	B, E, F	-

8-B	**Subnetwork 2→3**		**Subnetwork 3→2**		
Citing			Cited		
(0)	(46)	(52)	(0)	(46)	(52)
1 1980-89	2 1990-03	3 2004-12	1 1980-89	2 1990-03	3 2004-12
-	C	A	-	C	A
-	A	G	-	A	C
-	B	B	-	B	B
-	G	C	-	G	G, H
-	F, H	E	-	H	G, H
-	F, H	H	-	F	E, F
-	-	F	-	-	E, F
-	-	-	-	-	-

8-C	**Subnetwork 1→3**		**Subnetwork 3→1**		
Citing			Cited		
(224)	(501)	(215)	(224	(501)	(215)
1 1980-89	2 1990-03	3 2004-12	1 1980-89	2 1990-03	3 2004-12
C	A	A	C	B	A
B	G	B	B	C	C
A	B	C	A	A	B
G	C	F	G	G	F, G
F	H	G	H	H	F, G
H	F	H	H	H	F, G
E	E	E	E	D	E
D	D	D	D	E	D

Table 8. Citation link ranks and shifts of IPC classes A-H appearing in three sub-networks in three periods . –·–·-·–> signifies entry or exit of ISC class links between periods.



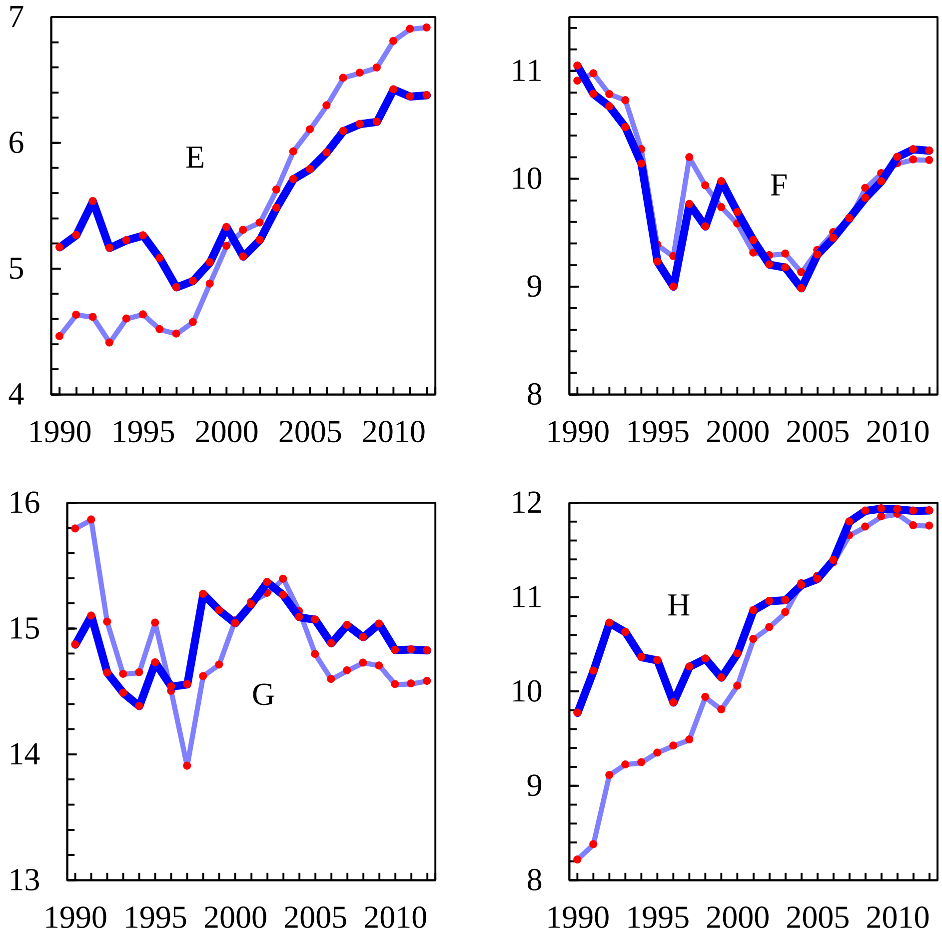


Figure 4. Changing shares of indegree (dark) and outdegree (light) by IPC class for complete cumulative network of links between country-specific IPC classes. Full network including all regional groups and flows as in Figures 1.