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Dynamics of Technology Upgrading of the Central and East European Countries in a Comparative Perspective: Analysis Based on Patent Data

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Abstract

This report explores patterns of technology upgrading as a three-dimensional process which consists of (i) intensity of technology upgrading, (ii) structural change, and (iii) interaction with the global economy. The specificity of our report is that we depict patterns of technology upgrading by relying entirely on patent data. We derive patent indicators to capture the three dimensions.

Patent indicators for intensity of technology upgrading trace technological capabilities at the technology frontier (transnational patents) and behind the technology frontier (domestic/resident direct applications to national offices). Structural change in technological knowledge is depicted by the share of transnational patent applications in high technology fields and knowledge-intensive activities and by calculating a technological diversification index. To capture interaction with global economy in the upgrading process indicators measure technological knowledge sourcing across countries and interactions between foreign and indigenous actors. Based on 7 patent indicators covering the three upgrading dimensions the comparative analysis focuses on EU27 and its subregions and on the BRICS countries.

According to the results, in 2011 CEECs were quite homogenous in their upgrading paths. A typical CEE economy in 2011 is well behind EU12 in terms of frontier technology intensity, domestic technology intensity, share of high tech patents and technology sourcing abroad. Moreover, its organizational capabilities are often less advanced. The CEE profile is much less coherent in terms of technology diversification/specialization and share of joint inventions. However, differences among CEECs are not significant. Still there are some notable national features. Poland, Romania and Slovenia have above average domestic technological intensity which reflects partly their sizes (Romania and Poland) and specific model of innovation system reliant on domestic R&D intensive firms (Slovenia). Latvia and Lithuania are specific in terms of high share of HTKI patents.

CEE technology upgrading as depicted by patents is within the BRIC pattern (with exception of China which in terms of technology upgrading has de facto delinked from BRICS). In the BRIC context, the CEE characterize very open innovation system with a high share of coinventions and foreign actors exploiting local inventions. This reveals weak organizational capabilities to commercialize its own inventions.

According to the results CEE grew during 1990s/2008 based on production, not technological capability. Their future growth will increasingly depend on building technological capabilities at world frontier level. Our analysis shows that the basis for such growth exists only to a limited extent and that speed of upgrading towards world frontier activities is well beyond required for catching up. Equally, our analysis shows that solutions for improved technology upgrading will need to be found with their existing innovation model of small open economies integrated into the EU.

1. INTRODUCTION

In this report we explore issues related to technology upgrading of the European Union (EU) peripheral economies, especially of the new EU member states[1]. Technology upgrading is the key to further long-term growth as suggested by the growth literature. This has been already recognised by the EU policy agenda which has promoted Smart Specialization Strategies (SSS) as the ex-ante conditionality for use of the EU Structural Funds to so call less favoured EU regions and countries. In addition, EU has been using the European Innovation Scoreboard as it was called in the past and now Innovation Union Scoreboard (IUS) as the major metrics in assessing progress of all EU countries in terms of their innovation capacity. This metrics has become so dominant that some of its either individual or aggregate indicators have been used as policy objectives and benchmarks in measuring how countries perform in achieving the aims of SSS and other national policy targets.

Central and Eastern European countries (CEECs) are largely middle-income economies but it is not certain whether they have achieved a threshold of technological capability required for catching up to high-income economies status[2]. The shift from middle income to high-income is not guaranteed or is not automatic as growth process is usually non-linear and evolves across several threshold levels with their specific threshold requirements. In order to understand this process we need to be open to a variety of historical experiences as well as go beyond simple explanations of growth be they adequate institutions (Daron and Robinson 2008), human capital (Glaeser et al. 2004) or Research and Development (R&D) (OECD 2004).

In order to advance research in this area we approach to the issue of growth and measurement of growth through the perspective of technology upgrading. This is a multidimensional conceptual framework which is open to sensitivities of different levels of development and which is also empirically informed but also has some theoretical relevance. We consider it as appreciative theorizing framework which aim to overcome a frequent weakness of composite indicators which is that they represent "measurement without theory" (Koopmans 1947). A conceptual approach is based on the literature review and is developed as part of this task in a paper by Radosevic and Yoruk (2014) *Why do we need theory and metrics of technology upgrading?* as part of this deliverable. Here we rely broadly on this approach but we also develop it further by applying it based on patent data.

The paper is organised as follows: We first explain approach to technology upgrading by discussing its elements (section 2). In section 3 we use this approach to analyse individual indicators of technology upgrading. Section 4 explores position of EU in technology upgrading in a comparative perspective of the EU28 and BRICS economies. In section 5 we explore three dimensions of technology upgrading. Section 6 concludes.

[1] By European periphery we mean neighboring countries, which are not members of the EU. These are West Balkan countries, Turkey, and European CIS countries

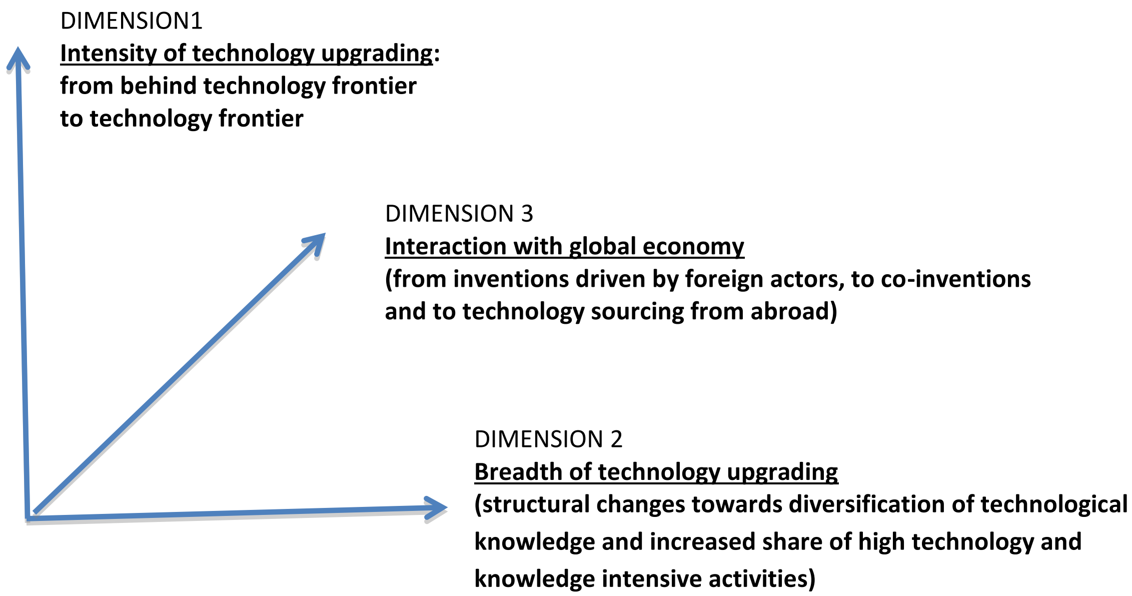
[2] Based on World Bank criteria only Bulgaria and Romania are middle income economies while others are in a high income group. However, from our perspective this classification is not suitable for categorising CEECs and for understanding middle income trap.

2. DETECTING TECHNOLOGY UPGRADING THROUGH PATENT DATA: A CONCEPTUAL APPROACH

Our departing proposition is that technology upgrading is multidimensional process. By this we mean that: it is based on broader understanding of innovation, which goes well beyond R&D. It is multi-level process which means that it is micro, mezzo and macro grounded but which also means that at its core is structural change in various dimensions: technological, industrial, organisational. It is also an outcome of global forces (embodied in international trade and investment flows) and local strategies (pursued by host country firms and governments)(for extensive review of literature on this issue see Radosevic and Yoruk 2014; for perspective along these lines see Ernst 2008;Lall 1992).

In nutshell, based on literature review and at general level we approach to technology upgrading as three-dimensional process. It consists of dimension 1: which is about intensity of technology upgrading as depicted by different types and levels of innovation activities, of dimension 2: which is about spread or width of technology like diversity of technological knowledge, and of dimension 3: which depicts knowledge inflows into economy through a variety of forms like trade, FDI and global value chains. All three dimensions have strong grounding in the respective literatures on firm level technology upgrading, on structural change and growth, and on integration in global economy. Figure 1 summarizes three dimensions and paths of technology upgrading.

Figure 1. Dimensions and paths of technology upgrading



Source: authors

In the technology upgrading process dimension 1 evolves from domestic behind technology frontier efforts towards world frontier technology efforts. Dimension 2 goes in direction of increasing diversification in terms of categories of technological knowledge and increasing share of knowledge in high growth or dynamic areas. Dimension 3 evolves from invention process being driven by foreign actors towards joint knowledge generation and then towards sourcing of technology from abroad. We aim at capturing these dimensions and their evolution using patent indicators.

The body of research on measuring countries' performance in growth, competitiveness and innovation offers a variety of composite indicators. Examples are: the Global Competitiveness Index (WEF 2012), the Knowledge Economy Index (Chen and Dahlman, 2004) of the World Bank, the World Competitiveness Report Index of IMD (http://www.imd.org/), Technological capability of countries and the ArCo, (Archibugi and Coco, 2005, 2004; Archibugi et al., 2009), the UNIDO Industrial Performance Scoreboard (UNIPS), the Summary Innovation Index and the Global Innovation Index, both of the European Commission; the Technological Activity Index of the UNIDO; the Technological Advance Index of the UNCTAD; the Technology Achievement Index, developed by UNDP and reported in the Human Development Report 2001, and the S&T Capacity Index (STCI) proposed by the RAND Corporation, the High-Tech Indicators (HTI) developed at the Georgia Tech Technology Policy and Assessment Center and reported by the National Science Foundation's Science & Engineering Indicators.

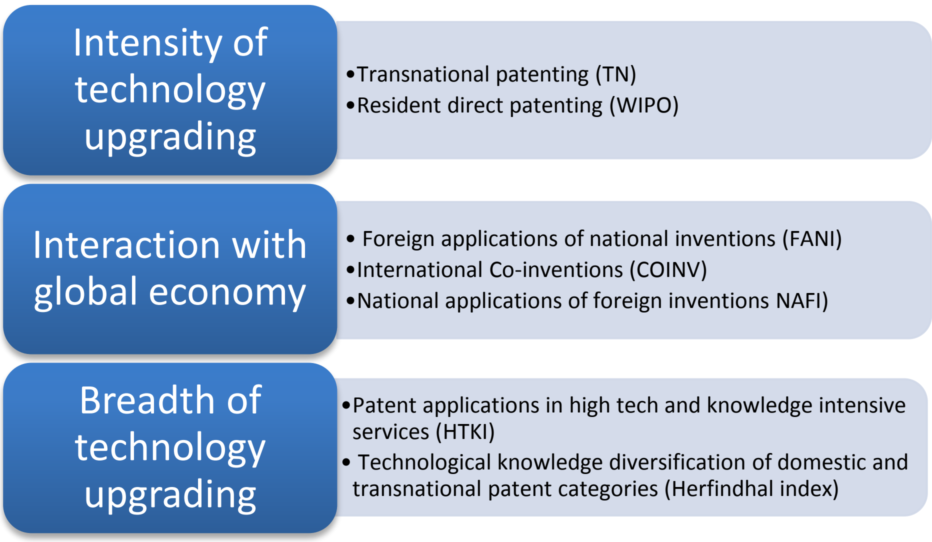
Nasierowski and Arcelus (2000) show that similarity in ranking across different indexes are significant. They all point to importance of innovation to economic development but differences in their conceptual perspectives do not change significantly ranking among countries. Archibugi et al. (2009) show similar results but also show that differences in ranking cannot be substituted by single indicator like R&D.

It is important to bear in mind that different indexes treat 'technology' in different ways. Some of them cannot be taken as a direct measure of innovative performance. Indicators like Global Competiveness Index depict the quality of the current endowment of a country (including institutions) and among them also the technology activities as one of determinants of growth. Our aim is to confine ourselves to technology upgrading and we do not aim to unravel a complex picture of the entirety of factors that determine growth and competiveness of economies. Also, unlike the majority of rankings, our aim is not really to focus on ranking but on different paths of technology upgrading. The learning effect should be in showing diversity of paths and compare countries in terms of their own upgrading paths.

The specificity of our paper is that we depict patterns of technology upgrading by relying entirely on patent data. On the one hand, the exclusive reliance on patents has costs in terms of capturing only a part of technology effort. Their intangible character is more advantageous as countries move up towards technology frontier and less relevant for countries behind technology frontier where IPRs are not the major form of protection of technological knowhow. This is especially important as innovation activities in latecomer economies like CEE are largely about adoption and improvements on imported machinery. Although, technology as stock of knowledge should be kept separate from production, technological capacities and production capacity are in reality strictly interconnected (Bell and Pavitt 1997). However, use of only patents means that similar to Archibugi and Coco (2005) we need to abstract production from technology capability. On the other hand, an important advantage of using patents is the length and consistency of time series derived as well as the possibility to identify technological fields or specializations using the patent classification. Unlike macroeconomic variables technological capabilities are changing very slowly even during periods of deep economic crises or high growth periods (Archibugi 2009). By using patents we can detect easily stock and flows and thus depict much better compared to other indicators changes in technology intensity as well as structural change in technological knowledge. These two dimensions – technology upgrading and structural change – should be considered jointly with the way economy integrates itself in global knowledge flows.

In overall, we think that benefits surpass costs in this case provided that we are aware of the changing nature of patenting as countries move from the position of technology followers to leaders and as they shift from domestic and behind frontier technology effort to world frontier technology effort. Figure 2 shows patent indicators used which depict individual dimensions of technology upgrading.

Figure 2. Dimensions and components of technology upgrading as depicted by patent indicators



Source: authors

2.1. INTENSITY OF TECHNOLOGY UPGRADING (SCALE)

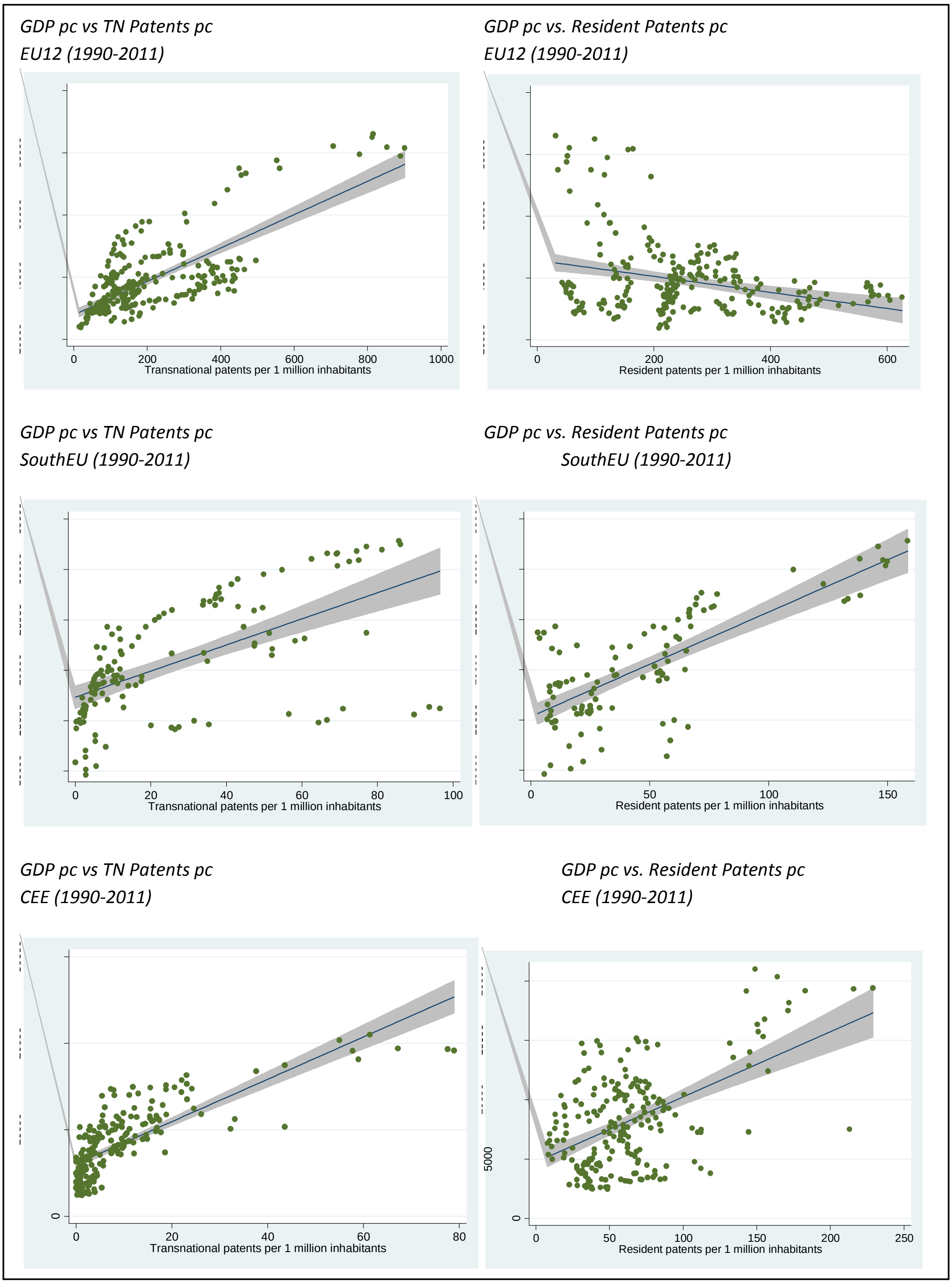
This dimension of upgrading is about acquiring different types of technology capabilities, which are also a reflection of different technological levels of economies. Economies that operate behind technology frontier are more likely to grow based on production capability while high-income economies are more likely to grow based on technology frontier (R&D based) activities. Three types of capabilities (production capability, technology capability, R&D) are present in all economies to different degrees. Their importance as drivers of growth varies in dependence of achieved income and technology levels as well as of the structural features of economies.

We use patent indicators to measure domestic technological capability. Nonetheless, for the analysis it is necessary to differ between domestic technological capability pushing the technology frontier and domestic technological capability for technological development behind technology frontier. To capture domestic technological activities pushing the technology frontier we rely on transnational patent applications of domestic applicants (TN). Transnational patent applications include applications to the European Patent Office and PCT applications. These patent filings reflect technological activities relevant for competitiveness in international markets. This international relevance of patent protection suggests that the technology protected pushes the technology frontier at a global level. To capture technological capability for technological development behind the technology frontier we use direct patent applications by residents to their respective national patent offices. In general terms (even though the patent strategies may differ from this rule) residents will directly apply for patents in their home countries disregarding applications abroad if their technological activities do not have a global industrial relevance.3 To us resident direct patent applications to national patent offices dominantly proxy technology effort behind the technology frontier. Countries that are behind technology frontier should have much higher share of resident patents and their share of transnational patents is marginal. However, as they move towards technology frontier their transnational patenting increases. This pattern may be somewhat different in very large catching up economies where domestic patenting may continue to play important role. However, their transnational patenting as proxy of world frontier technology effort should continue to increase.

Figure 3 shows on the left the relationship between transnational patents applications per capita (TN) and GDP per capita for the EU12 (developed or core EU), South EU (Greece, Portugal and Spain) and the EU CEECs over 1990-2012 period. On the right Figure 1 shows same relationship but for WIPO patents per capita i.e. for domestic technology effort. The relationship is much better for transnational patents which indicate close relationship with levels of GDPpc.

[3] We are aware that this strategy is much more relevant for smaller than for larger and more developed economies where due to their economic size we may expect that more patents will be registered as priority patents i.e both at home and abroad than in small economies. However, this factor in analysis is controlled by patents by GDP proxy.

Figure 3. Technology intensity at the frontier and behind the frontier vs GDP pc.



Source: RegPat, World Bank and authors' calculations

2.2. TECHNOLOGY UPGRADING AND STRUCTURAL CHANGE

There is not general theory of structural change but a variety of theoretical approaches of different methodological nature that aim to explain structural shifts between three broad sectors and among industries within these sectors (Krueger 2008). There is a common understanding that technological changes affect structural change in the way that industries with relatively lower rates of productivity growth tend to shrink in terms of shares while those with higher rates of productivity growth expand. In this way structural change promotes aggregate productivity growth even if we assume that within industries productivity growth remains stagnant. However, the empirical evidence on the role of structural change in aggregate productivity growth escapes broad generalisations. It generates positive as well as negative contributions to aggregate productivity growth. Since many of these effects net out, structural change on average appears to have only a weak impact (Peneder, 2003). So, instead of being focused on structural changes at the level of industries it seems more appropriate to track changes in the structure of technological knowledge.

We depict structural change in technological knowledge by using two indicators. First, transnational patent applications in high technology fields and knowledge-intensive services. Second, we use technological diversification index based on Herfindhal index of transnational patents across 35 technological fields. This index is based on Lee (2013) who shows that catching up from middle income to high income status is accompanied by diversification of technological knowledge.

We should expect that latecomer economies have initially highly concentrated structure of patents which are diversifying as they are upgrading technologically i.e the number of patents categories with patents is increasing. This process should be present in the case of both resident and transnational patents. However, we would expect that dispersion of technology effort should be more pronounced in the case of transnational than resident patents. Also, we may expect that as countries are catching up that they are increasingly involved in high growth patenting areas which are in high tech categories and in knowledge intensive services areas.

2.3. TECHNOLOGY UPGRADING AND INTERACTION WITH GLOBAL ECONOMY

A successful technology upgrading is never entirely autonomous process but is always linked to inflow of foreign knowledge skills, which are coupled with intensive domestic technology effort (Radosevic 1999). The key to catch-up and post-catch-up is leverage of domestic innovation efforts with global industrial or knowledge networks (Dieter 2008). Hence, magnitude of knowledge inflows and their coupling to domestic innovations efforts are important dimensions of technology upgrading. A globalisation of technology exploitation and collaboration but also technology generation through globalization of R&D process has further increased the importance of international linkages for industrial upgrading (UNCTAD, 2005). Drawing on the Cross-border Ownership approach by Guellec and van Pottelsbergue (2001, 2010) we use patent indicators to gauge technology sourcing from foreigners as well as interaction or cooperation in technological activity with foreign actors. Guellec and van Pottelsbergue (2001, 2010) developed the concept of the Cross-border Ownership to explore globalization of RD process. We use the indicators from the perspective of technology upgrading which leads to slightly different interpretations. Technology sourcing from a global perspective and the nature of interaction with foreign actors change from the catch up to the post catch up stage, which is reflected in patent indicators. We use three indicators to explore these processes.

Foreign Applications of Native Inventions (FANI) measure the extent to which technological development in a country or region is driven by foreign actors. This is primarily important in the catch-up phase of host countries. If we assume that inventors have the technological capabilities and applicants exploit these capabilities commercially, this indicator is a proxy for the involvement of foreign actors in the exploitation of native technological capabilities.

International Co-invention in technological activities (COINV) measure international collaboration using patent applications with inventors residing in different countries. The share of patents involving inventors from different countries shows the degree to which knowledge generation is internationalized.

Native Applications of Foreign Inventions (NAFI) is a proxy for the exploitation of technological capabilities abroad as it measures the extent to which technological development in a country is making use of knowledge or technology sourcing from abroad. Arguably, this element becomes increasingly important in the later stages of the catch-up phase of host countries and might characterize high-income host countries. In that respect, it may be expected that countries behind technology frontier have high share of FANI, are increasingly involved in COINV and have smaller share of NAFI. As they are technology upgrading it may be expected that share of FANI declines, while shares of COINV and NAFI are increasing.

3. TECHNOLOGY UPGRADING THROUGH PATENT DATA: COMPARATIVE ANALYSIS

Based on this conceptual framework in this section we analyze patterns of technology upgrading of the CEECs but in a comparative context of the EU28 and BRICS economies. We consider CEE countries individually as well as groups of EU countries to analyze the convergence process in Europe between 1990 and 2011. The groups of countries considered are EU12, EU South and CEE. Indicators for these group of countries are built using the average across countries within the respective group (CEE, EU12, South EU). Moreover, CEE are compared to BRICS. We follow dimensions of technology upgrading as explained in section 2.

3.1. Intensity of technology upgrading

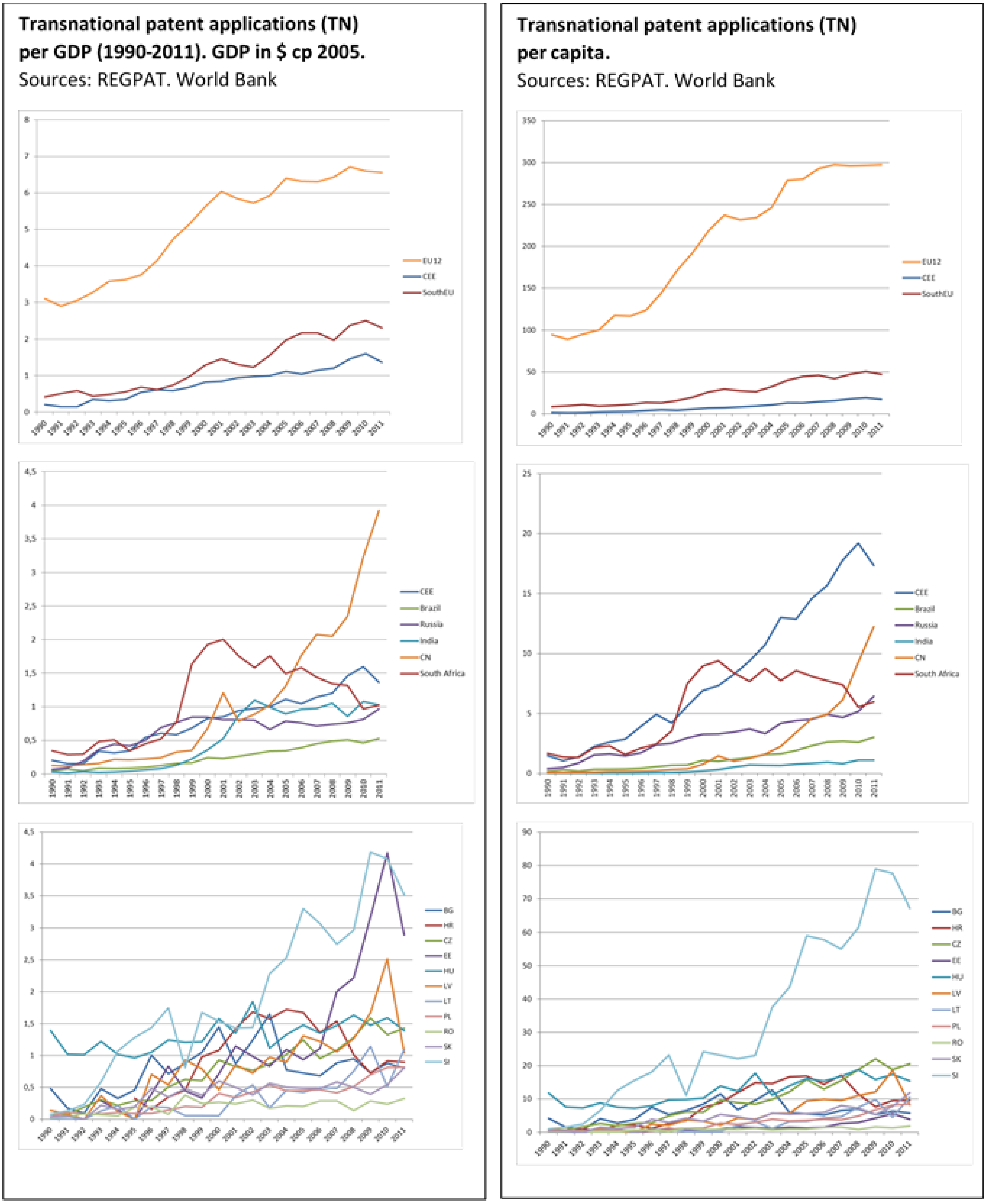
As mentioned above, intensity of technology upgrading is reflected on the technology capability of the country. To capture domestic technological capability pushing the technology frontier we rely on transnational patent applications of domestic applicants compiled from the OECD RegPat Dabase (Version January 2014). To capture technological capability for technological development behind the technology frontier we use direct patent applications by residents to their respective national patent offices. The World International Patent Office (WIPO) provides with data on direct applications by resident applicants to their national offices.

3.1.1. Technological capability pushing the technology frontier

Drawing on Frietsch and Jung (2009) the counts of transnational patents (TN) include all PCT applications whether transferred to the EPO or not and all direct EPO applications without precursor PCT application.4 We consider two indicators: Transnational patent applications per GDP (TNpGDP) and Transnational Patent Applications per capita (TNpc). TNpGDP captures the technology intensity of the economy at the technological frontier. TNpc capture the technology intensity of the country. Figure 4 includes the indicators for different CEE countries and group of countries.

[4] The origin of the invention is defined by the country of residence of the applicants. The indicators use the applicant country for the geographic designation of the invention in order to be consistent with the data available from WIPO. The application year (rather than the priority year) is considered for the same reason. If an invention involves applicants from different countries each country will be assigned with one application (and not a fraction of it).

Figure 4. Indicators to capture technological capability pushing the technology frontier



Source: OCED RegPat, World Bank and authors' calculations.

In what concerns the European Union, per GDP and per capita indicators of technological intensity display strong growth from early 1990s and deceleration of this process after 2008. Within EU the data suggest a divergence on core and periphery countries. This is especially present in terms of growth of patents until 2008 when patenting in the developed EU12 slows down.

The comparison of CEE with BRICS suggests that in pc terms CEE has higher 'technology intensity of country' (not economy) than China. China's catch up started in 2000s not in 1990s as CEE. So, this is quite recent phenomenon which is telling about technology upgrading of China. A strong catch up CEE in per capita terms is lost in GDP terms while Chinese is not. In other words, CEEC as countries have become more patent (technology) intensive but not as economies. The increasing/decreasing gap between TN patenting in pc and GDP terms is an indicative proxy for increasing or decreasing alignment or misalignment of their National Innovation Systems (Tunzelmann et al. 2012).

In the group of CEE countries Slovenia is the clear leader in terms of transnational patents per capita. This can be reflection of its very high relative GERD, its high income but also its profile of R&D system which may be geared more towards patentable sectors especially pharma and chemicals (OECD 2012, p. 108). Estonia is second leader largely. Slovenia is outlier in per capita terms but joined with Estonia in GDP terms. Both countries are still above China but given differences in size this is remarkable for China and puts all CEE successes in perspective. Among CEECs, it is interesting to see that continuous growth of Poland is reflected in transnational patents per GDP. Given still very small numbers we consider this to be the reflection rather than driver of growth.

3.1.2. Technological capability behind the technology frontier

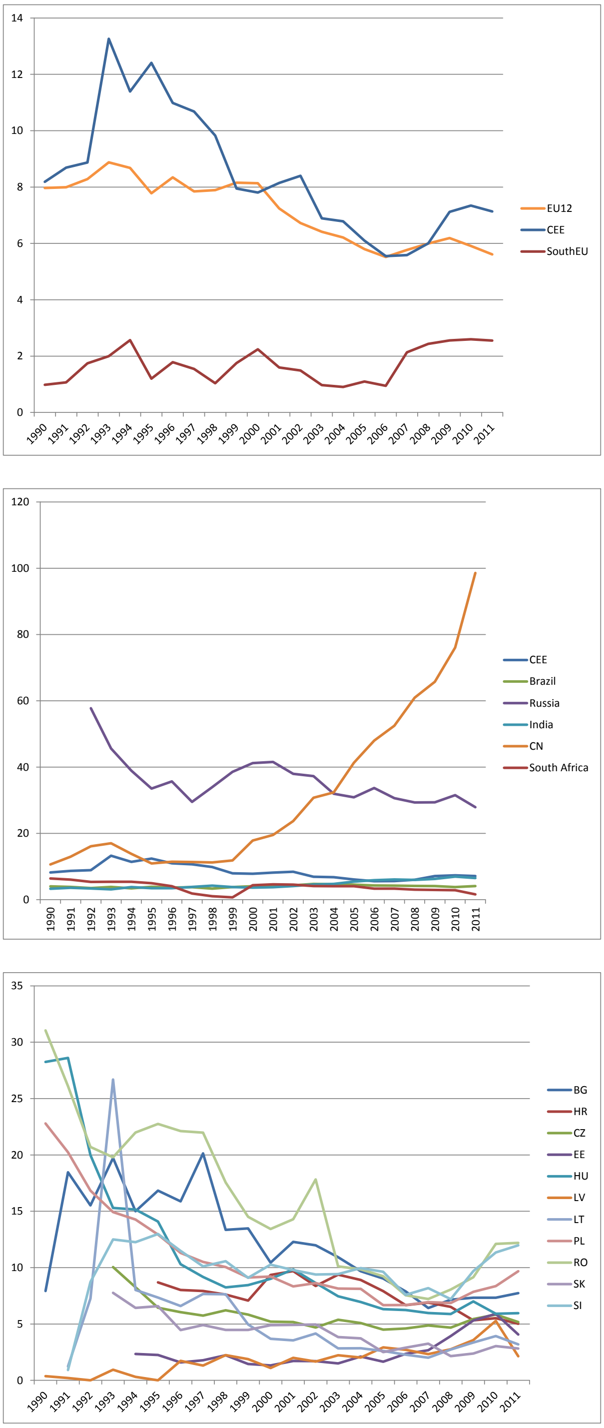
Analog to the use of transnational patents we build per GDP and per capita indicators for the period 1990-2012. Figure 5 presents the patent indicators per application year.

In overall, there seems to be much less increase in technology intensity of country in terms of direct applications to national offices (behind the frontier effort) than in terms of TN patents (at world frontier). This is expected given decrease in demand for domestic behind frontier effort when compared to imported technology. A stagnant trend in EU28 and in its subregions shows the declining importance of technology efforts oriented towards local/national markets (see figures 1 and 2 above). This may be expected given continuous economic and institutional changes towards European research area and effects of industrial networks in the EU, especially between Germany, Austria and Central Europe. Some increase in CE and South EU after 2008 is difficult to interpret except as the effect of Structural Funds (at least in CEE and increase in GERD/GDP ratios).

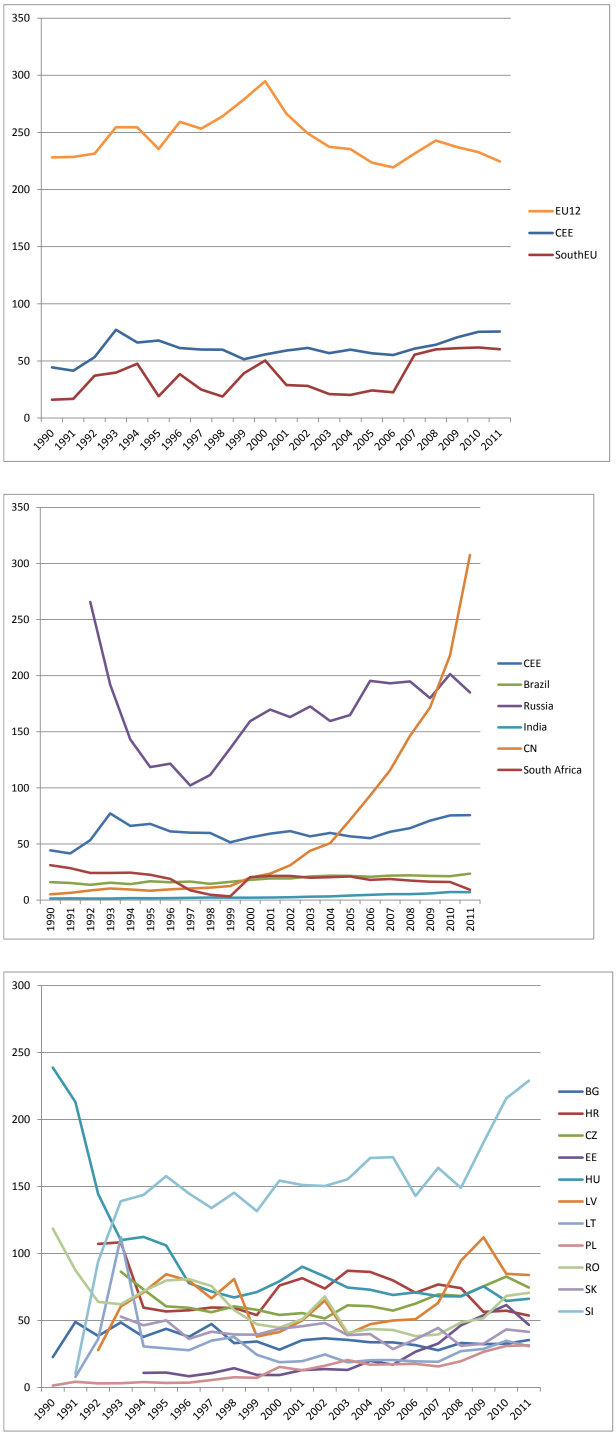
A higher number of direct resident applications per GDP in CEE when compared to the EU12 shows that in terms of behind the frontier technology effort CEE were high in early 1990s, especially given significant decreases in their GDP. On the other hand, a decline of resident patents per GDP in CEE shows increasing internationalization of their economies where behind the technology frontier effort is being increasingly squeezed by opening of their innovation systems. Hence, we observe a strong convergence. However, it seems that the level has now stabilized and even slightly increased as the effect of 2008. This is also the case in the EU South.

Figure 5. Indicators to capture technological capability behind the technology frontier

Resident direct patent applications per GDP (1990-2011). GDP in $ cp 2005.
Sources: WIPO, World Bank



Resident direct patent applications per capita.
Sources: WIPO, World Bank



Source: OCED RegPat, World Bank and authors' calculations.

In what concerns the comparison between CEE with BRICS, China shows a strong increase of both behind and on the frontier technology effort. So, in the case of China we do not observe hyper integration features of India or closed economy of Russia but there are elements of coupling between domestic and technology frontier. Russia is unique in its persistent and high levels of behind the frontier technology effort. This is quite expected given the nature of its system of innovation

Within CEE Slovenia is again leader in terms of ‘technology intensity of country’ (not economy): A strong increase after 2008 in Slovenia is probably due to effects of Structural Funds in support of domestic RTD system, especially centres of excellence and competence centres.

3.2. Breadth of technology upgrading

To analyze breadth of technology upgrading we focus on features of structural change. This is about widening ‘surface’ of technology efforts or increasing number of technology areas in which countries get involved or patent as they progress in technology upgrading. We define two structural change indicators to measure this process: (i) the relevance of high technology and knowledge intensive services patents in the technological activities and (ii) the diversification of the technological activities across 35 technological fields.

3.2.1. High Tech Knowledge Intensive Patents

Using transnational patent applications we consider the share of patents in the high technology fields and knowledge intensive services (HKTI). To define high technology we use the EUROSTAT definition.5 The indicator used is the share of HTKI patent applications to the total patent output in the country per application year. We frame HTKI patents as patents that reflect high growth technology areas or ‘dynamic technology frontier patenting activities’.

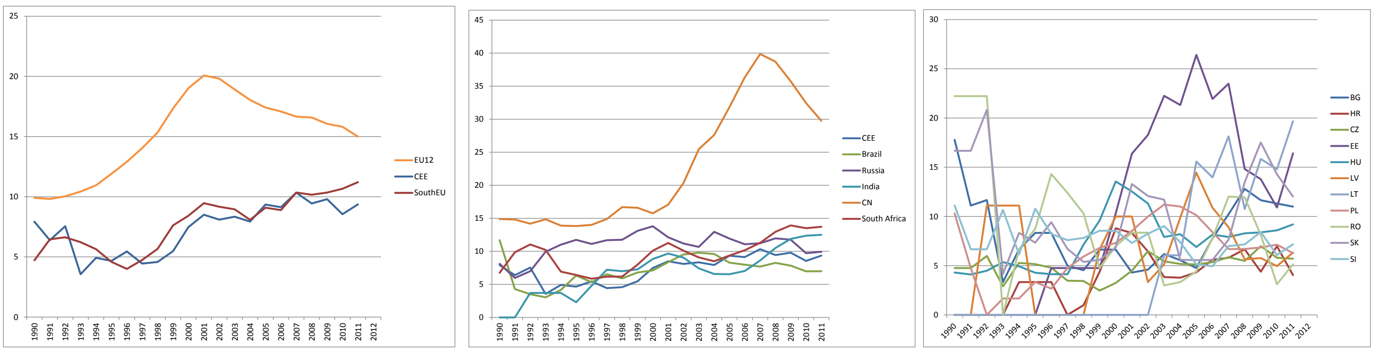


Figure 6. Share of HTKI Patents in total patent output per application year (3 Years MA)

Source: OCED RegPat and authors’ calculations.

Figure 6 shows the indicator for different countries and groups of countries. The share of HTKI patents at technology frontier is on average 6% in CEE, 11.4% in EU15 and 6.1% in South EU. In the EU periphery technology activities in currently growing and dynamic areas related to ICT presumably are underrepresented. This seems to correspond to an analysis on based priority patents (Dominguez Lacasa and Giebler 2014). However, there is a positive structural change of shifting towards HTKI

[5] http://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an6.pdf (last accessed 13.01.2015)

areas which is strikingly similar in both EU South and CEE. A decline in share of HTKI areas at the EU15 level shows that technology path of EU is quite different from US or East Asia.

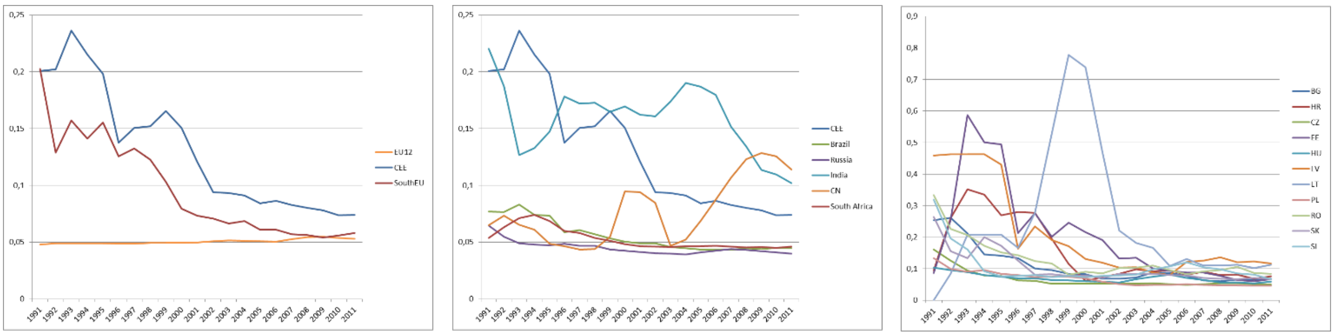
BRICs shows a gradual but upward increase in the share of HTKI patents with China having the highest share but also decline in the share after 2007/08. This maybe reflects a changing orientation of Chinese growth towards more domestic technology based growth (after 2008) and technology diversification in transition from middle to high income as argued by Lee (2013). The indicator for China nicely shows that its boom does not have anything to do with dot.com wave in 2001. The same holds for the other BRIC countries. This suggests that the nature of globalization is largely about absorptive capacities of catching up countries not catching up at frontier (Radosevic and Yoruk, 2014, OECD 2010). It is quite surprising to observe a low share of HTKI of India given possible hypothesis on 'hyperintegrationist' mode of development as opposed to China. Interestingly, they are on two different sides within the BRICS spectrum. Within the BRICS the biggest surprise is India which shows that its technological strengths in services are not yet in services that can be captured by patent indicators. Its export of software is not of patentable type.

In general terms CEE falls clearly within BRIC spectrum even in terms of secular increase in share of HTKI areas.

3.2.2 Technology diversification

Drawing on Lee's (2013) idea that catching up process translate into an increasing diversification of technological activities we aim at analysing trends in diversification of technological capabilities. To measure technological diversification we use the Herfindhal index of transnational patent applications and resident direct patent applications to the national offices across 35 technological fields (Schmoch 2008). The assignment of an invention to a technological sector or specific technology field follows a fractional counting methodology.6 The Herfindhal index is normalized between 0 and 1. Values close to 1 mean concentration. Values close to 0 mean diversification.

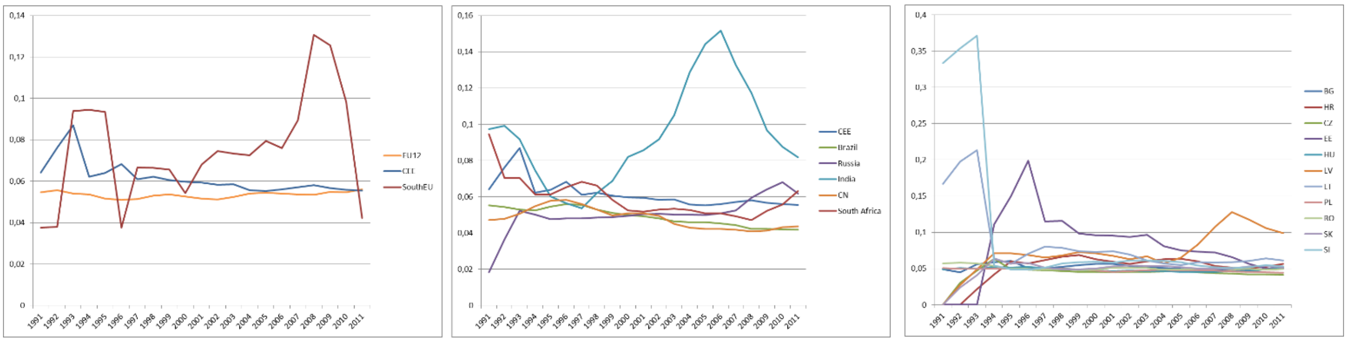
Figure 7. HH-Index: Transnational Patents (3 Years MA)



Source: OCED RegPat and authors' calculations.

[6] If a transnational patent application includes patent classes that belong to different technological areas or technologies a fraction (and not a whole count) will be considered for each technological area or technology.

Figure 8. HH-Index: resident direct patent applications to the national offices (3 Years MA)



Source: OCED RegPat and authors' calculations.

The indicators presented in Figures 7 and Figure 8 suggest a clear trend towards diversification which is in line with Lee's (2013) hypothesis and results except for China for TN patents and for India for domestic patents. .

For TN patenting, trends in the EU periphery shows strong diversification though at a somewhat higher levels of concentration in CEECs than in the EU South. A diversification trends is feature of all CEECs despite their quite different starting levels of concentration/diversification. There is strong convergence of both the EU South and CEE to the core which presumably should mean that the overall technological knowledge structure in the EU is becoming strongly determined by the EU core. However, this trend has slowed down significantly after 2001 despite economic growth which was high until 2008.

Trends towards diversification of technological knowledge are also feature of the BRICs except China after 2000. First, we observe very strong diversification of India and CEE which suggest technology upgrading via diversification. Second, there is a very slow diversification trend in Russia, Brazil and South Africa which may reflect slow structural change in their technology systems. Third, China shows opposite trend – towards concentration or decrease in number of transnational patent categories. How do we interpret this seemingly counterintuitive trend? Has China already moved towards technology structure of the upper income economies? Lee (2013) shows that diversification is trend in transition from middle to upper income stage after which countries continue to specialize. China does not seem to conform to this trend.

As we would expect diversification is much less pronounced in resident patenting which largely reflect domestic and behind the frontier technology effort. The slow tendency towards diversification is present in all countries with exception of India after 1997, South EU after 2001 and China after 2004. Without in depth analyses of each regions technology systems it is quite difficult to interpret structural changes in generation of technological knowledge behind technology frontier. Also, we see need for further research in exploring diverging vs. converging trends between structural change of TN and resident patenting.

3.3. Interaction with the Global Economy

In general, the key idea here is to use patent based indicators to gauge technology and knowledge flows as well as interaction or cooperation in technological activity with foreign actors. The flows and the modes of interaction with foreign actors change along the catch up process, which should be reflected in the indicators. We use three indicators originally developed by Guellec and van

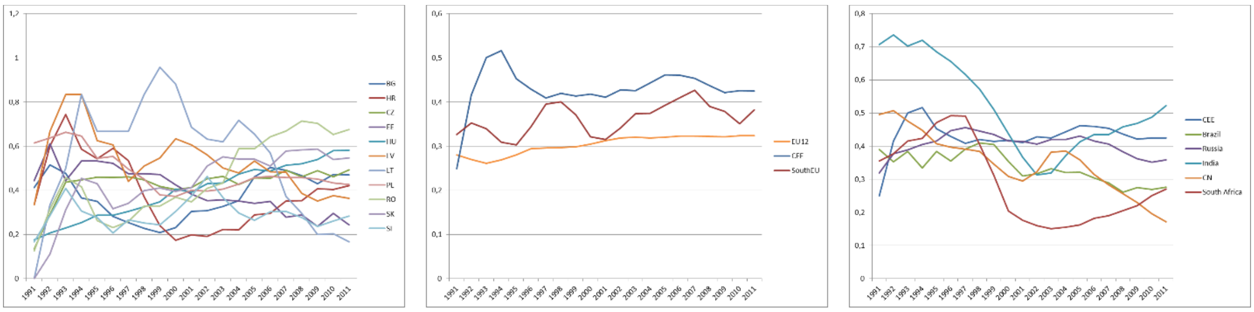
Pottelsbergue (2001, 2010) to track technology sourcing from a global perspective and international knowledge cooperation.

3.3.1. Foreign applications of National inventions (FANI)

FANI shows the share of TN patents that are invented by inventors in country x but applicants are from country y. Guellec and van Pottelsbergue (2001, 2010) interpreted the indicators as the extent to which technological development in a country or region is driven by foreign actors. A large FANI Rate suggests the strong importance of foreign actors exploiting the technological activities of a country or region. A low FANI Rate suggests that native inventions are mainly applied by native actors. If we assume that inventors have the technological capabilities and applicants have commercial and organizational capabilities this indicator can tell us something about the relationship between technical and non-technical capabilities. According to Teece (1986) for successful innovation and technological development at the firm level it is not enough to have technology capabilities but also complementary assets to put these capabilities into use. At firm levels this means organisational capabilities in addition to only invention capacity. His answer to who actually profits from innovation, pointed to owners of complementary assets, particularly when they are specialized and/or co-specialized. So, following Teece (1986) we interpret large FANI as a proxy for organisational capabilities of firms or individuals to commercialize inventions on their own. For firms that are applicants of foreign inventions this indicates presence of organisational capabilities to commercialize inventions as well as understanding of available technological inventions abroad which are patentable.

From the perspective of complementary or organizational capabilities, a declining FANI rate all else equal is a sign of upgrading in complementary or organisational capabilities in the country or capacity to profit from their technological activities. Figure 9 presents the indicator for different countries and group of countries.

Figure 9. Rate of Foreign Applications of Native Inventions (FANI Rate) (3 year MA)



Source: OCED RegPat and authors' calculations.

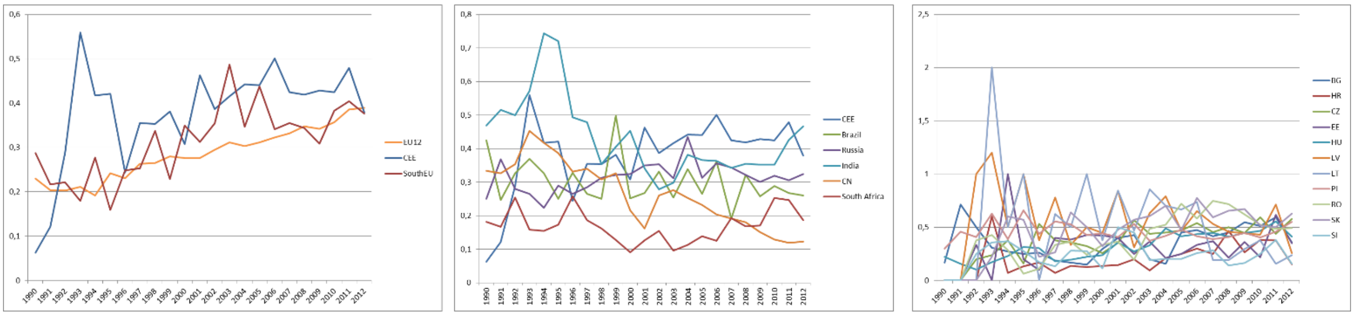
From the complementary or organisational capabilities view, the sudden increase in FANI Rate in 1990-1993 in CEE is a reflection of weak organisational capabilities of firms in newly opened economies to handle invention process on their own and also of better understanding of foreigners what are available technological inventions which are patentable. However, situation has stabilised and if we take mid-1990s as the beginning of normal period we do not observe improvements in organisational or complementary capabilities. In fact, average between 1995-1998 and 2010-2012 shows a minor decline in all CEECs. We observe similar weakening of complementary capabilities in South EU as well as in the EU12. This trend can be a reflection of weakening of these capabilities across Europe (i.e. of declining role of EU large firms as organisers of innovation processes) but this can also be a reflection of globalisation of innovation process.

Given our interpretation of FANI we would expect that successful technology upgrading would be reflected in decreasing FANI. Data for BRICs and CEE are in line with this hypothesis. For example, China's FANI rates have declined dramatically reflecting organisational power of Chinese MNEs. Indian complementary capabilities as reflected in FANI have improved until 2001/2002 (dot.com period) and have declined afterwards as reflected in increased FANI indices. Russian and especially Brazilian FANI Indices are gradually and slowly decreasing reflecting gradually improving complementary capabilities of their firms, especially MNEs. Within BRIC context CEE FANI rates seems quite stagnant reflecting possibly very weak endogenous organisational capabilities i.e a low share of domestic large firms in technology activities.

3.3.2. Indicators for Knowledge Cooperation: Coinventions (COINV)

As countries upgrade technologically their capability for joint international generation of inventions should increase. An increase in joint patents also reflects changing nature of invention process which is becoming more globalized as depicted also by FANI and NAFI indicators. Guellec and van Pottelsbergue (2001, 2010) measure international collaboration using patent applications with inventors residing in different countries: the share of patents resulting from international research co-operation (inventors from different countries) in the total number of patents invented by residents of a given country. Here we use identical measure.

Figure 10. Share of International Co-Inventions (COINV Rate) (3 year MA)



Source: OCED RegPat and authors' calculations.

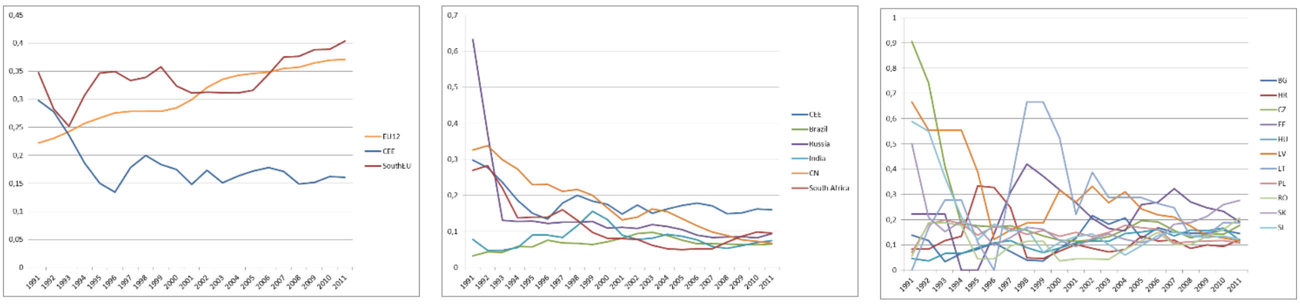
As given in Figure 10, the indicator shows significant globalization of knowledge generation in the EU and in its three sub-regions. By 2012 in all three sub-regions of the EU around 40% of all TN patents applications involve at least one foreign and one domestic inventor (COINV). However, there are significant differences in trends between three sub regions. At EU periphery there seems to be stagnation in COINV rates after 2001 (South EU) but especially after 2008 (South and CEE). This may possibly reflect the effect of worsening of macroeconomic conditions after 2008 on R&D based investment and thus on technology knowledge co-generation.

Levels of technology co-generation are lower in BRICS than in the CEE and the rest of the EU. Among BRICS China is distinctive as its share of co-inventions declines continually reflecting much stronger patenting by Chinese companies themselves. Hence, this relative decline should not be confused with absolute very strong growth of Chinese TN patents. Russia and Brazil again have similar trend of stagnant COINV rate but given size of these economies the share of co-inventing is actually quite high. India's patenting was during the 1990s more than half based on co-inventions but COINV was also rapidly declining reflecting increasing indigenous technological capabilities. After 2001 India has been increasingly involved in technology cooperation at very high level for such large economy. Again, compared to China it is on the other side of the BRIC spectrum. Its share of technology co-inventions is similar now to the CEE which is a much smaller region.

3.3.3. National Application of foreign Inventions (NAFI)

Drawing again on Guellec and van Pottelsbergue (2001, 2010) we compute the share of transnational patent applications with applicants located in a country that involve at least one inventor located abroad. This indicator is a proxy for the exploitation of technological capabilities abroad (Native Applications of Foreign Inventions - NAFI). These patent-based indicators aim at measuring the extent to which technological development in a country is making use of knowledge or technology sourcing from abroad. Arguably, this element become increasingly important in the later stages of the catch-up phase of host countries and might characterize high-income host countries. The operationalization follows the logic outline for FANI above. Counting transnational applications per application year, the number of transnational patents applied by natives and invented by foreigners and (NAFI) is divided by the total number of transnational patents with at least one national applicant (NAFI-Rate). From the perspective of technology upgrading, we interpret the capacity of countries to source technology from abroad as measured by NAFI as the sign of high or increase organizational capabilities all else equal. A high or increased NAFI would indicate improvement in these capabilities and vice versa.

Figure 11. Rate of Native Applications of Foreign Inventions (FANI Rate) (3 year MA)



Source: OCED RegPat and authors' calculations.

Figure 11 includes NAFI rates for different countries and groups of countries. NAFI indices for EU regions shows that technology sourcing abroad has initially declined in CEE and has remained stagnant and at comparatively very low level since mid-1990s while it has increased significantly at EU12 and South EU. Surprisingly levels of NAFI for EU12 and South EU are relatively similar which should reflect similar capacities for technology sourcing abroad. Among CEECs, there were initial differences in NAFI but these have been gradually converging as times goes by. NAFI, which in our context denote capacities for technology sourcing abroad, have been stagnant in BRICs which may seems surprising given the newly emerging literature and evidence on emerging markets MNEs, some of which have relied on technology sourcing as one of their strategies orientations. In particular, declining NAFI of China seems to suggest that despite individual high profile cases of BRICS MNEs sourcing technology abroad these cases do not yet represent trend or technology sourcing is not their key strategic orientation. However, we should bear in mind that NAFI or share of transnational patent applications with applicants located in a country that involve at least one inventor located abroad is quotient and we should bear in mind that it is dependent on total number of TN patents. A catching up country that has high and growing number of TN patents but still low number of its patents invented abroad is actually doing still better than country that has high NAFI but low number of its TN patents. This is exactly the case between the CEE and China where former has higher NAFI but much lower number of TN patents.

4. TECHNOLOGICAL UPGRADING IN EUROPE IN A COMPARATIVE PERSPECTIVE

In this section we merge three dimensions and all indicators into one graphic form – network diagram - to explore levels and patterns of changes of technology upgrading. Each graphic includes 7 indicators. The technological intensity of a country is represented by the number of patent applications by residents at the national filing office per GDP (domestic technological intensity) and the by the number of transnational patent applications by national applicants per GDP (frontier technological intensity). The breadth of technological upgrading is represented by share of high tech knowledge intensive transnational patent applications in total transnational patent applications (High tech patents) and the degree of concentration of patent applications by residents at the national filing of the country across 35 technological areas (specialisation). The technological interaction with the global economy is represented by three indicators: The share of applications with at least one national applicant and at least one foreign inventor in total transnational inventions filed by at least one national applicant (NAFI Rate); the share of foreign applications with at least one foreign applicant and at least one national inventor in total transnational applications with at least one national inventor (FANI Rate); and the share of transnational patent applications involving at least one foreign as well as one domestic inventor in the total number of transnational patent applications invented by at least one native (COINV Rate).

First, we analyze each of the CEE countries in comparison to other EU countries at a particular point in time (2011). In a second section we explore the position of the CEE in relation to BRICS using identical approach.

4.1. Technological upgrading in the EU

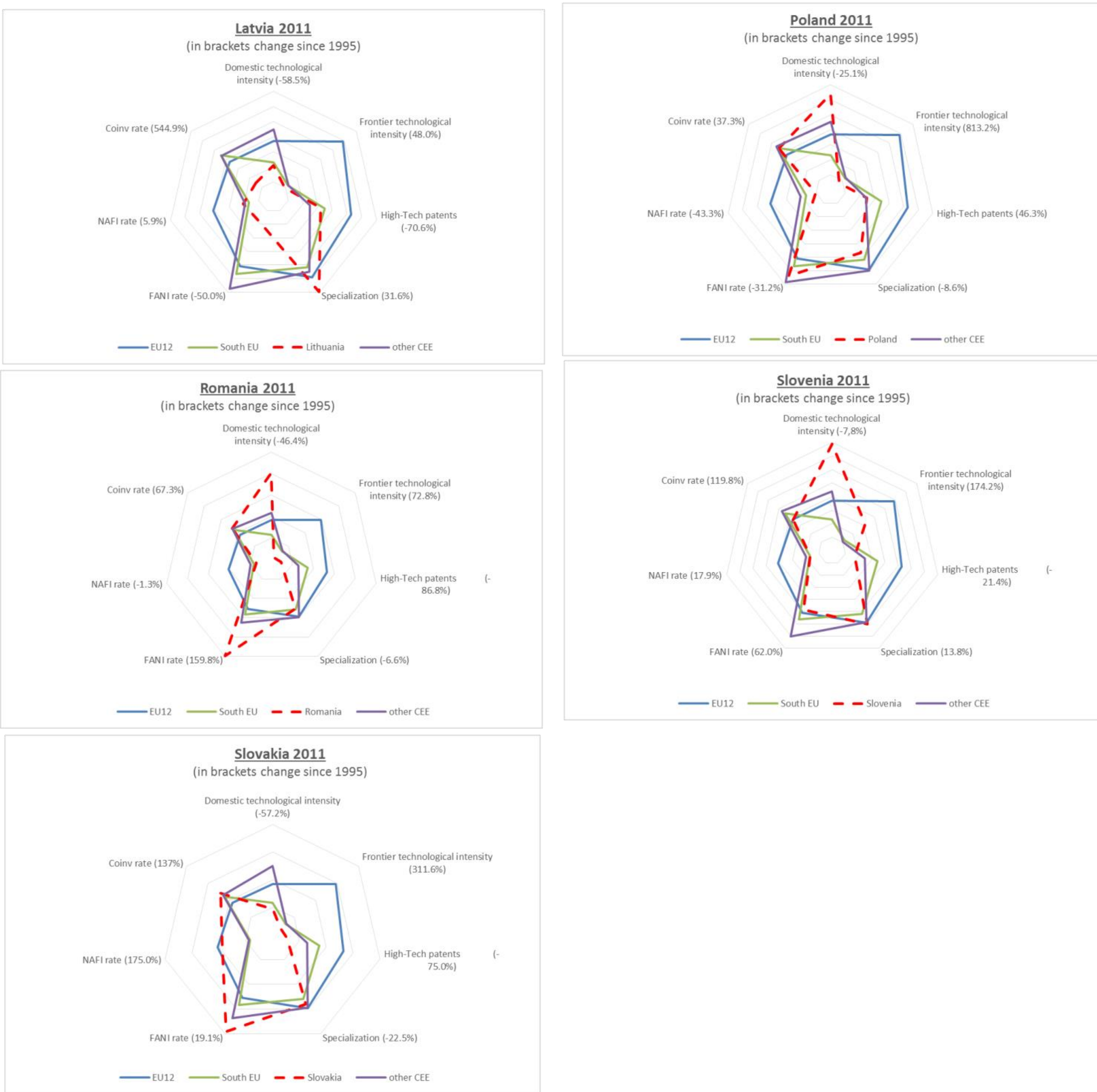
We consider the seven indicators for CEE countries for the year 2011. In addition, we indicate the relative change in percent for each indicator for the respective CEE country in comparison to the year 1995 (or the latest available). In the diagrams we compare each of the eleven CEE countries to the other ten CEE countries, South European countries as well as EU12 countries. The values for each indicator used for graphical representation are scaled between 0 and 1 using all country values for 26 EU countries. Then we generated simple unweighted average for the other ten CEE countries, the group of South European economies as well as the group of the EU12 countries. Thus, the graphical space represented by the seven dimensions in each of the diagrams corresponds to the possible maximum values by 26 EU countries at the point of observation (2011).

Figure 12 and Figure 13 bellow show the profile of technology upgrading of the individual CEECs in relation to the EU12, South EU and other CEECs. We do not go into detailed description of profiles of each of 11 CEECs but draw only two general conclusions. First, technology upgrading profiles of the CEECs are pretty homogenous which reflects their technological levels and relative distance to the EU-12. A typical CEE economy is well behind EU12 in terms of frontier technology intensity, domestic technological intensity, share of high tech patents and technology sourcing abroad (NAFI). Its organizational capabilities are often less advanced as reflected in high share of FANI. The CEE profile is much less coherent in terms of technology diversification/specialization and share of joint inventions. Second, differences among CEECs are not significant in the sense that we can talk of distinct national technology profiles. Poland, Romania and Slovenia have above average domestic technological intensity which reflects partly their sizes (Romania and Poland) and specific model of innovation system reliant on domestic R&D intensive firms (Slovenia). Latvia and Lithuania are specific in terms of high share of HTKI patents.

Figure 12. 2011 Indicators for Bulgaria, Czech Republic, Estonia, Croatia, Hungary and Lithuania. Comparison with EU 12, South EU and other CEE

Source: OCED RegPat, WIPO, World Bank and authors' calculations.

Figure 13. 2011 Indicators for Latvia, Poland, Romania, Slovenia, and Slovakia. Comparison with EU 12, South EU and other CEE



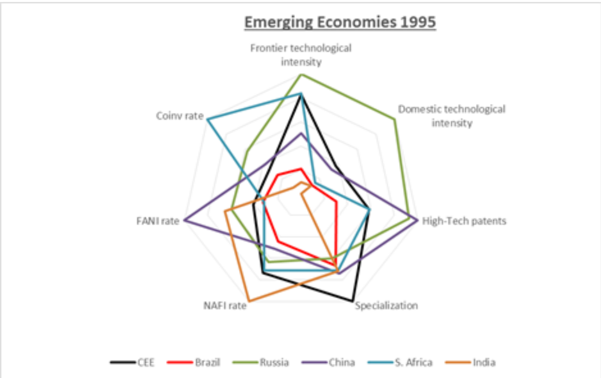
Source: OCED RegPat, WIPO, World Bank and authors' calculations.

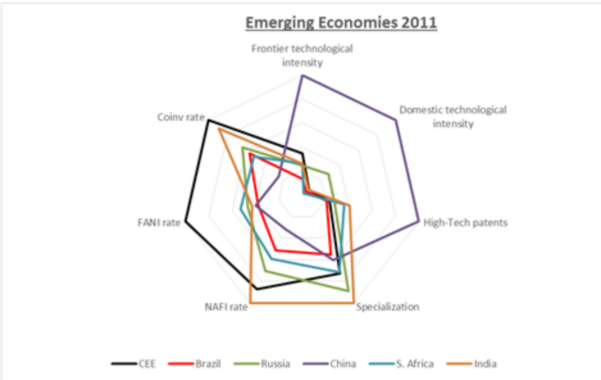
4.2. Technological upgrading of Emerging Economies

Again, using network diagrams we aim at a graphical presentation of changes in the selected indicators for each of the three dimensions of technological upgrading for the CEE region in comparison to the BRICS countries between 1995 and 2011.

First we create two summary network diagrams that integrate all countries under observation in 1995 and 2011 to show the change in structural indicators in these selected emerging economies and the CEE region (Figure 14). Next, we offer a diagram for the CEE region and each of the BRICS countries (Figure 15) based on seven indicators in 1995 and 2011. The values for BRICS are country specific. For the CEE region we create a simple unweighted average for across the eleven CEE countries. Before drawing the graphs, we scale all indicators for the BRICS countries and the CEE region between 0 and 1. Thus, the graphical space represented by the seven dimensions in each of the diagrams corresponds to the possible maximum values by the BRICS countries and the CEE region in 1995 and 2011.

Figure 14. Indicators for BRICS and CEE (average) in 1995 and 2011





Source: OCED RegPat, WIPO, World Bank and authors' calculations.

A comparison of the CEECs and BRICS profiles in 1995 and 2011 offers few very interesting insights. First, 1995 profiles are more diverse than 2011 reflecting divergences and convergences among these catching-up economies. In 1995, Russia had distinctive prolife characterised by comparatively the highest both domestic and frontier technological intensity and together with China the highest share of high tech patents. CEE had the least diversified technological knowledge portfolio with comparatively high frontier technological intensity. China had the highest FANI rate which by 2011 became the lowest next to Brazil reflecting increase organisational capabilities of their MNEs to commercialize their own inventions. India had very low ranking on all dimensions of technological upgrading except in terms of NAFI or sourcing technology abroad. This quite diverse set of profiles changed significantly by 2011. China has delinked from BRICS by highly increased domestic and frontier technological intensity as well as by very high share of high-tech patents. CEE has lost its initial high ranking in terms of frontier technological intensity, has significantly diversified its technological knowledge, increased co invention rate but also became the region with the highest FANI rate which reflects weak organisational capabilities to commercialize its own inventions. India has continued to be comparatively the strongest in sourcing technology abroad but it also reduced diversification of its technology portfolio of inventions. Other BRICS – Russia, Brazil and South Africa – have features which fall within these three specific cases of China, CEE and India. Russia has lost its advantages in terms of the highest frontier and domestic technological intensity. In overall, we have seen a shift from much more diverse technology upgrading profiles in 1995 towards four profiles: China, CEE, India and rest of BRICS (Russia, Brazil and South Africa).

Next, we explore in greater detail changes in between 1995 and 2011 by each of BRICs and CEE (Figure 15). CEE technology upgrading profile has substantially changed in between 1995 and 2011. Its technology intensity, both at frontier and domestic, has been declined and its openness has significantly changed as shown by increased co-invention, NAFI and FANI rates. On positive side, its technology profile has diversified as should be expected when countries are transiting from middle towards high income status. Also, its capacity for sourcing technology abroad has also somewhat improved. However, invention process in CEE has become much less intensive but it is now taking place in cooperation with foreign partners (COINV) who have organisational capabilities to commercialize local inventions (NAFI). The CEE case contains interesting lessons regarding costs and benefits in terms of openness and autonomy of technology systems.

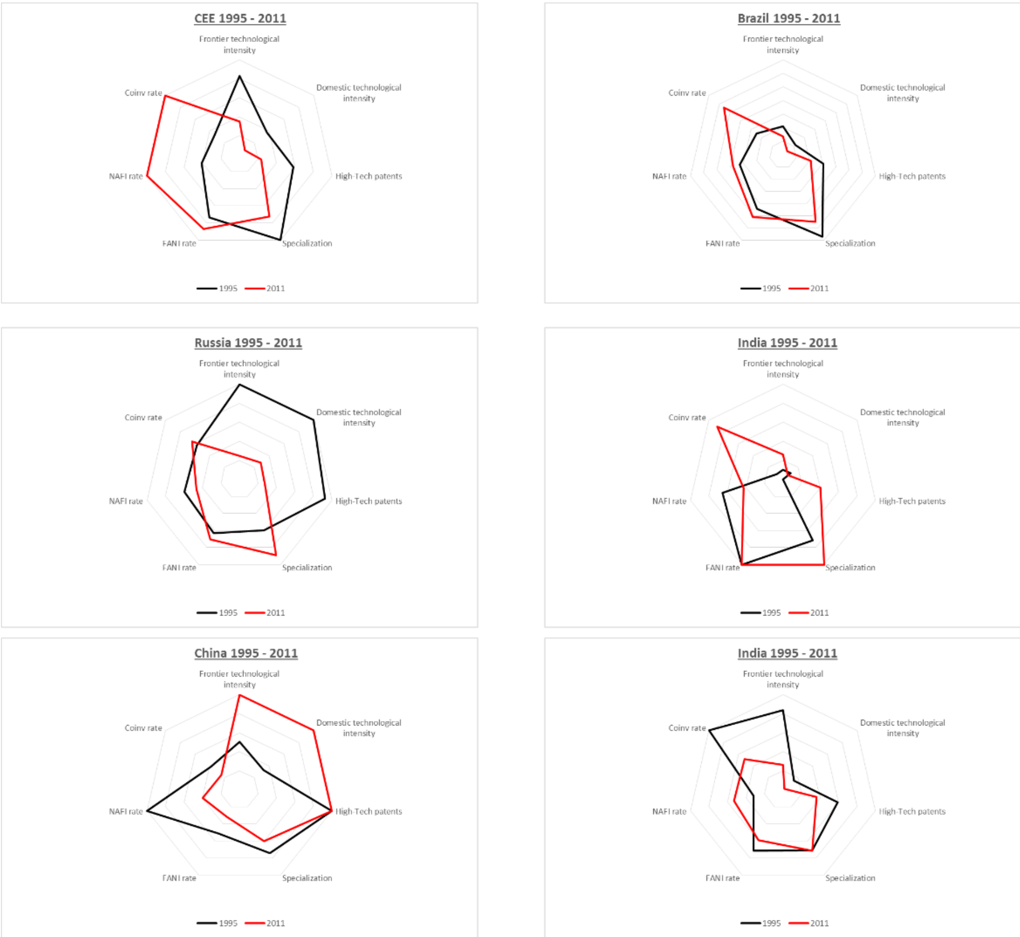
Changes in profile of Russian technology upgrading have been similar but also much more dramatic when compared to the CEE. First, its decline of frontier and domestic technological intensity has been much sharper than in the CEE. Also its share of high tech patents has significantly declined. This loss of technology intensity of CEE has been compensated by stringer interaction with global economy through high coinvention rate which was not the case in Russia. Also, its FANI and NAFI rates have remained relatively unchanged. As in CEE, there has been positive tendency of increased technological diversification.

China's profile of technology upgrading shows very strong increase in both domestic as well as in frontier technological intensity at the same share of high tech patents. On the other hand, technological upgrading was not followed by its increased technological openness. Its coinvention rate has dropped significantly and its capacity for sourcing technology abroad has declined somewhat. FANI rate for China has declined dramatically which actually shows increased capability of its MNEs to commercialize their own inventions. Given huge increases in China's technological intensity this dimension of interaction with global economy should be seen in relative terms as relatively less intensive given much higher increase in technological intensity. In this respect, a Chinese model of technology upgrading is quite different from the CEE which had to compensate its decreasing technological intensity by more technological openness.

India has very low technological intensity which despite its high economic growth in this period has further shrank questioning whether its further growth can rely on technology or on other production factors. Similar to CEE India has to compensate much less dramatic loss of technology intensity by increase knowledge cogeneration (COINV). Its capacity to source technology from abroad has remained constant but its technology portfolio has further concentrated which is not the best basis for technology upgrading of such a large economy.

Changes in Brazilian technology upgrading profile have been much less intensive when compared to China, Russia, and CEE. Relatively small decreases in technology intensity and in share of high tech patents have also resulted like in CEE and India to increases in knowledge cogeneration at relatively similar NAFI and FANI rates. South Africa followed similar pattern as its domestic and especially frontier technology intensity have declined as well as share of high tech patents. As in Brazil, CEE and India this has led to increases in co-invention rates and with slight changes in NAFI and FANI rates at unchanged degree of technology diversification.

Figure 15. Indicators for BRICS and CEE (average) in 1995 and 2011



Source: OCED RegPat, WIPO, World Bank and authors' calculations.

5. EXPLORING DIMENSIONS OF TECHNOLOGICAL UPGRADING

So far, we focused on identifying differences and changes to the technological profile of CEE countries in comparison to other European economies and the BRICS countries by using selected patent based indicators. In the final part of the analysis, we aim to explore all three dimension of technological upgrading: technology intensity, structural changes and knowledge interaction with global economy. We have departed from the proposition that technology upgrading is multidimensional process and these three dimensions are different facets of this complex process.

Statistically, it is possible to create a simple composite indicator of technological upgrading based on selected indicators across countries within the observation period. In order to this, we need to make some assumptions about the relation between our indicators and technological upgrading. This seems straight forward in case of technological capability or intensity. Here we assume that a higher value for technological intensity with regard to domestic or frontier technology corresponds to a higher stage in technological development of the country. Second we assume that the breadth of technological upgrading is higher, if the share of high tech knowledge intensive patents in transnational patent applications is higher as well as the degree of diversification of domestic technological activity across technological areas is higher. Finally, we assume that higher NAFI rates (i.e. transnational patent applications with national applicants and foreign inventors) correspond to stages of higher technological development as capacity of countries to source technology globally increases. In turn, we assume that lower FANI rates (i.e. transnational patent applications with foreign applicants and national inventors in total transnational inventions) corresponds to stages of higher technological development as countries organisation capabilities to commercialize inventions generated in their own country increases. Finally, we assume that COINV Rates (i.e. transnational patent applications involving at least one foreign as well as one domestic inventor in the total number of transnational patent applications with national applicants) should decline as countries develop technology capability to invent but also to commercialize their own inventions.

However, we think that constructing a composite indicator of technology upgrading would defy our main analytical aim in this paper which is to understand the interactions between different dimensions of technology upgrading and their changes. 'Burying' different dimensions and their interactions into one composite indicator is in contradiction to our departing proposition to build metrics which takes into account different drivers of technology upgrading. Synthesizing three relatively independent but related processes – *technology intensification, structural changes and knowledge exchange* - into one indicator leads to decontextualized metrics. Given generally poor understanding of the processes of technology upgrading each of the above stated assumptions can more or less stand scrutiny but only as a stylized fact on its own. However, we are much less certain about their mutual interaction and whether the overall construct or composite indicator of technology upgrading is really theoretically and statistically grounded.

In view of these limitations as well as of the greater learning potential in exploring different dimensions of technology upgrading, we present summary sub-indexes for each of three dimensions of technology upgrading. Our analysis uses information for 1995 and 2011.The results are presented in Table 1. Following the above outlined assumptions we inverse the original values for the indicators Herfindhal, FANI Rate and COINV Rates for each country. Using values for the year 1995 (or the earliest year available) we rank each of the seven indicators separately, where the highest value corresponds to the highest rank. Then we add the ranks across the relevant indicators for each dimension for each country. The ranking of technological intensity is based on measures for domestic and frontier patenting intensity. The measure of diversification of domestic inventions and the relative importance of inventions in high tech and knowledge intensive activities are grouped into the indicator for structural changes. Finally FANI, NAFI and COINV rates are group into the ranking of interaction with the global economy. We give each indicator equal weigh into one composite indicator for each dimension. The country with the lowest sum has the highest overall rank per dimension. The procedure is repeated for the 2011 values. Finally we can identify relative changes in the ranking for each of the country between 1995 and 2011 in each dimension of technology upgrading. It is important to realize that this is not composite indicator of the overall technology upgrading but of upgrading as reflected in patent data. In that respect, this indicator shares all virtues and drawbacks of patents as indicators.

We need to acknowledge that the five indicators used to measure breadth and global interaction of technological upgrading are measures independent from the underlying 'size' or intensity of patenting activity. For example, similarly low FANI rates (i.e. high rankings) are obtained in case of Malta and Finland in 2011. However, Finland has the second highest technological intensity and Malta is ranked 22. The FANI rate is calculated with a base of 39 transnational patent applications in case of Malta and with 2.324 in case of Finland. The distortion is amplified in case of the NAFI rates. As a result Malta comes in first on the ranking for global interaction. Similar cases apply basically to all CEE countries in the year 1995 and to the majority of smaller CEE countries (Baltic economies) still in 2011. Given the upward bias in the rankings of structural change and global interaction for countries with low or very low frontier or domestic technological intensity, we need to interpret the ranking dynamics of the corresponding countries with appropriate caution.

Having these limitations in mind the ranking dynamics suggest the following:

1. ***<u>Technological intensity:</u>*** China has increased by far the most its patenting intensity due to remarkable increase of both TN and resident patents. Still, Germany and Finland are two of the most technology (patent) intensive economies. Given their income levels China and Slovenia are surprisingly highly located. This indicates their high potential for technology upgrading but also it shows that their current growth is not yet based on R&D. Russia's relatively high position is largely due to domestic technology effort. CEE (with exception of Slovenia) are firmly in the second half of table together with South EU which is expected given that drivers of their growth are not related to technology but to production capability.

Table 1. Dimension of technology upgrading: patent-based rankings 1995-2011

	Technological intensity			Structural Change			Global Interaction		
Country	**1995**	**2011**	**Change**	**1995**	**2011**	**Change**	**1995**	**2011**	**Change**
Germany	2	1	1	6	26	-20	13	11	2
Finland	1	2	-1	5	2	3	10	2	8
China	18	3	15	15	1	14	19	23	-4
Slovenia	7	4	3	16	30	-14	5	16	-11
France	8	5	3	3	5	-2	14	9	5
Denmark	12	6	6	12	15	-3	12	8	4
Austria	10	7	3	21	20	1	11	13	-2
Sweden	3	8	-5	2	6	-4	6	3	3
Latvia	14	9	5	30	31	-1	28	22	6
Netherlands	13	10	3	9	14	-5	3	5	-2
Russia	4	11	-7	7	29	-22	25	30	-5
Romania	16	12	4	31	32	-1	31	25	6
United Kingdom	6	13	-7	1	4	-3	18	18	0
Luxembourg	19	14	5	29	23	6	23	6	17
Hungary	9	15	-6	24	22	2	26	32	-6
Italy	15	16	-1	8	25	-17	4	26	-22
Estonia	33	17	11	32	8	24	30	12	18
Poland	20	18	2	19	13	6	27	29	-2
India	30	19	11	27	24	3	17	33	-16
Czech Republic	22	20	2	13	18	-5	9	27	-18
Bulgaria	5	21	-16	11	11	0	24	21	3
Malta	28	22	6	33	33	0	1	1	0
Belgium	21	23	-2	4	9	-5	16	14	2
Ireland	11	24	-13	14	10	4	15	4	11
Croatia	17	25	-8	18	21	-3	21	28	-7
Spain	25	26	-1	10	3	7	8	19	-11
Lithuania	26	27	-1	23	27	-4	33	10	23
Cyprus	27	28	-1	25	17	8	7	7	0
Brazil	29	29	0	22	12	10	22	31	-9
South Africa	23	30	-7	20	19	1	32	24	8
Greece	31	31	0	26	16	10	29	20	9
Portugal	32	32	0	28	7	21	2	17	-15
Slovakia	24	33	-9	17	28	-11	20	15	5

Sources: OCED RegPat, WIPO, World Bank and authors' calculations. Authors calculation.

The underlying indicators for technological intensity are strongly shaped by industry structure and favor those economies where 'patenting industries' like chemicals and pharma are important. This partly explains the relatively high position of Slovenia. As technology intensity measure does not differentiate between frontier and behind the frontier patenting some economies will be higher than expected (Russia, Romania) or lower than expected (United Kingdom, Ireland). Based on patenting intensity BRICs are not homogenous entity but widely differing group with thus very different opportunities for growth based on technology.

Beside China the biggest improver in terms of technology intensity (in relative ranking) are Estonia and India. Bulgaria and Ireland have fallen substantially behind similar to fall behind of Russia, Romania, Croatia and South Africa.

2. ***Structural changes*** as depicted through indicators of patent diversification and shift towards high tech patenting is favoring countries behind the frontier as they have much more scope for convergence or reaching structure of the frontier economies. China and Estonia are again the biggest improvers, which is quite important additional evidence of their technology upgrading given that China is third ranked and Estonia 17th in terms of technological intensity. The biggest improver in terms of structural change is actually Portugal but it has also a fairly low technological intensity.

The smallest structural changes can be observed for Russia and Germany but for quite different reasons. Germany is at the technology frontier and it may be expected that it will further specialize. In fact, several technology intensive and high income economies are located very low in terms of technology diversification (Germany, Austria, Denmark, Italy). Finland is quite specific in the sense that it is technology intensive economy but also with high degree of diversification of patent portfolio. As we would expect it has reached limits of diversification and thus has not further improved in that respect. Russia in contrast lost considerable ground in terms of frontier and domestic technological intensity, which seems to have been paralleled by a narrowing diversification of domestic technological activity as well as a massive drop in the share of high tech patenting.

As outlined above our underlying approach is aimed to measure technology upgrading of middle income economies towards high income. This is clearly visible from changes in relative position in terms of structural change where five economies from the bottom group in terms of technology intensity are major diversifiers in expected direction while from the top group only China belongs to the biggest diversifiers. Germany as economy at technology frontier has reached saturation in that respect and has been actually specializing. So, within our framework indicators of structural change do not have a priory positive or negative interpretation. This depends on where countries stand in relation to the technology frontier.

3. ***Global interaction*** in patenting inventions is composed of three indicators (FANI, COINV and NAFI rates) that indicate different stages and modes of interaction with global economy as countries are technologically upgrading. So, identical change in degree of openness should be interpreted in the context of technological level of economy and the actual mechanism of interaction. The biggest changes in terms of increased openness in patenting activities took place in Lithuania, Estonia, Luxemburg and Ireland while the biggest relative 'withdrawals' took place in Italy, Portugal, Slovenia, Czech Republic and Spain. It is interesting to see that 'globalizaton of technology' is not universal process but evolves very unevenly reflecting very much country specific interactions between national technology systems and external environment.

The Chinese system is quite autonomous given its high technology intensity and direction of structural change in patenting portfolio. Latvian technology system has generated in narrow technology area high technology intensity but unlike neighboring Lithuania it is actually very little open in terms of knowledge exchange. On the other hand, Finnish system is technology intensive, quite diversified and also very open by being ranked second in terms of interaction intensity. Also, Swedish system is quite open and relatively highly ranked in terms of both diversity of patent portfolio and technology intensity. Slovenia as very technology intensive economy has not opened in terms of knowledge exchange but it has actually closed further in relative terms. Italy as large EU economy has further 'delinked' while its technology intensity remains medium.

With the exception of South Africa the BRICS have in relative terms not further opened up but actually have reduced their ranking positions in terms of global interactions at very different levels of technology intensity. For example, China and India reduced the relative ranking positions in terms of global interaction with increasing technological intensity, whereas Russia lost relative ground in terms technological intensity as well as global interaction. This is contrasted by the development in South Africa, which also observed drop of its relative position in terms of technological intensity but at the same time score relatively higher in terms of global interaction. This raises interesting issues about the role of autonomy and openness in technology system in the catching-up process. However, our data only allows the interpretation of changing positions in global interaction in relative terms looking at EU and BRICS economies. Each of them may have become more or less open in their own terms as we observed above.

6. CONCLUSIONS

This report measures patterns of technology upgrading as three-dimensional process which consists of (i) intensity of technology upgrading, (ii) structural change, and (iii) interaction with the global economy. All three dimensions have strong grounding in the respective literatures on firm level technology upgrading, on structural change and growth, and on integration of technological activities in the global economy. We compare countries in terms of technological levels and changes along their own upgrading paths as reflected in these three dimensions.

The specificity of our report is that, considering the 3 dimensions, we depict patterns of technology upgrading by relying entirely on patent data. This has its major advantages in terms of length and consistency of time series derived as well as in the possibility to identify technological fields or specializations based on patent classifications.

The indicators for intensity of technology upgrading trace technological capabilities at the technology frontier and behind the technology frontier. Transnational patent applications (TN) capture inventions pushing the technology frontier while resident direct patent applications to national patent offices dominantly proxy technology effort behind the technology frontier. It may be expected that as countries technologically upgrade their patent intensity increases and shifts form resident toward TN patents.

Structural change in technological knowledge is depicted by using transnational patent applications in high technology fields and knowledge-intensive services and by a technological diversification index based on Herfindhal index of transnational patents across 35 technological fields. Drawing on Lee (2013[7]) we assume that technology upgrading of middle income economies is depicted by increasing diversification of their technology profiles in terms of patents while this is not necessarily the case with high income economies.

To capture interaction with global economy in the upgrading process we focus on technological knowledge sourcing across countries and interactions between foreign and indigenous actors. We draw on indicators developed by Guellec and van Pottelsbergue (2001, 2010). We apply them for exploring technology upgrading which leads to new perspectives in their interpretation. Technology sourcing and the nature of interactions with foreign actors change from the catch up to the post catch up stage, which is reflected in patent indicators. We use three indicators. Foreign Applications of Native Inventions (FANI) measure the extent to which technological development in a country or

[7] Lee, K. (2013) Schumpeterian Analysis of Economic Catch-up Knowledge, Path-Creation, and the Middle-Income Trap. Cambridge University Press.

region is driven by foreign actors. International Co-invention in technological activities (COINV) measure international collaboration using patent applications with inventors residing in different countries. Native Applications of Foreign Inventions (NAFI) measure the extent to which a country is able to exploit technological knowledge from abroad. It may be expected that countries behind technology frontier do not have the organizational capabilities to exploit their own technological knowledge which is then exploited by foreign actors (high share of FANI), they increasingly interact with foreign partners for technology development (increasing COINV) but do not have the capabilities for exploiting foreign knowledge by themselves (smaller share of NAFI). As they are technology upgrading it may be expected that share of FANI declines, while shares of COINV and NAFI are increasing.

Based on these indicators and modes of interpretation our comparative analysis focuses on EU27 and its subregions (EU-12, CEE and South EU) and on the BRICS countries. We identify the following developments.

In terms of **intensity of technology upgrading** we observe different trends in the accumulation of technological capabilities at the technology frontier and behind the technology frontier, especially in what concerns CEE.

On the one hand, all parts of the EU28 have increased their technological capabilities pushing the technology frontier. TN patenting in the EU display strong growth from early 1990s and deceleration of this process after 2008. Within EU the data suggest a divergence on core (EU12) and periphery (CEE and South EU) countries which has been especially present until 2008 when patenting in the developed EU12 slows down.

The comparison of CEE with BRICS suggests that in pc terms CEE has the highest TN patents in pc terms. However, CEE are well behind China in terms of TN per GDP or in technology intensity of economy as measured by TN patents. Nonetheless, CEE is ahead of other BRICs. In terms of technology intensity at the world frontier CEE has advanced but it is beset by structural issues as reflected by big difference between lower technology intensity of its economy vs. higher intensity of country.

On the other hand, when it comes to technology effort behind technology frontier as measured by resident patents we observe a stagnant trend in EU28 and in its subregions. This may be expected given continuous economic and institutional changes towards European research area and effects of industrial networks in the EU. A strong decline of resident patents per GDP in CEE is the effect of their increasing internationalization and substitution of domestic technology effort by opening of their innovation systems.

In terms of **structural change**, there is a shift towards HTKI areas in both EU South and CEE towards EU12 shares. This is reflection of the strong convergence of both the EU South and CEE to the core which presumably means that the overall technological knowledge structure in the EU is becoming strongly determined by the EU core. However, a decline in share of HTKI areas at the EU12 level shows that technology path of EU is quite different from the US or East Asia. CEE falls clearly within BRIC spectrum in terms of share of HTKI patents.

What concerns the diversification of patent portfolios, there is a clear trend towards diversification in BRICS and CEE except for China in terms TN patents and for India in terms resident patents. A diversification trends is feature of all CEECs despite their quite different starting levels of concentration/diversification. As we would expect, diversification is much less pronounced in resident patenting which largely reflect domestic and behind the frontier technology effort.

With regard to technology upgrading and **the interaction with global economy** in terms of technology sourcing and interaction with foreign actors, the results for CEE match our expectations to some extent. Given our interpretation of FANI we would expect that successful technology upgrading would be reflected in decreasing FANI. Data for CEE and for BRICS are in line with this hypothesis. Within BRICS context CEE FANI rates seem quite stagnant reflecting possibly very weak endogenous organisational capabilities i.e a low share of domestic large firms in technology activities. Another strong feature of the CEE is a high share of coinventions. In all three sub-regions of the EU around 40% of all TN patents applications involve at least one foreign and one domestic inventor (COINV). Levels of technology co-generation are lower in BRICS than in the CEE and the rest of the EU which may be expected.

Interestingly, NAFI Rates for EU regions show that technology sourcing abroad has initially declined in CEE and has remained stagnant and at comparatively very low level since mid-1990s while it has increased significantly at EU12 and South EU. NAFI, which in our context denote capacities for technology sourcing abroad, have been stagnant in BRICs which may seems surprising given the newly emerging literature and evidence on emerging markets MNEs. It seems that despite individual high profile cases of BRICS MNEs sourcing technology abroad, these cases do not yet represent trend or technology sourcing is not their key strategic orientation.

To identify specific technology upgrading paths for the different regions and countries we develop **technological upgrading profiles** involving al indicators. These upgrading profiles have been used for the comparative analysis in 2011 and 1995.

In 2011 **CEECs** were quite homogenous in their upgrading profiles which reflects their technological levels and relative distance to the EU-12. A typical CEE economy in 2011 is well behind EU12 in terms of frontier technology intensity, behind frontier technology intensity, share of high tech patents and technology sourcing abroad (NAFI). Moreover, its organizational capabilities are often less advanced as reflected in high share of FANI. The CEE profile is much less coherent in terms of technology diversification/specialization and share of joint inventions. However, differences among CEECs are not significant in the sense that we can talk of distinct national technology profiles. Still there are some notable national features. Poland, Romania and Slovenia have above average domestic technological intensity which reflects partly their sizes (Romania and Poland) and specific model of innovation system reliant on domestic R&D intensive firms (Slovenia). Latvia and Lithuania are specific in terms of high share of HTKI patents.

Technology upgrading profiles of **BRICs and CEECs** for 1995 are more diverse than for 2011 reflecting divergences and convergences among these catching-up economies. CEE had the least diversified technological knowledge portfolio with comparatively high frontier technological intensity. By 2011 CEE has lost its initial high ranking in terms of frontier technological intensity, has significantly diversified its technological knowledge, increased co invention rate but also became the region with the highest FANI rate which reflects weak organisational capabilities to commercialize its own inventions. On positive side, its technology profile has diversified as should be expected when countries are transiting from middle towards high income status. Also, its capacity for sourcing technology abroad has also somewhat improved. However, invention process in CEE has become much less intensive but it is now taking place in cooperation with foreign partners (COINV) who have organisational capabilities to commercialize local inventions (NAFI).

These changes in the CEE technology upgrading profiles contrast well with BRIC countries. Changes in profile of Russian technology upgrading have been similar but also much more dramatic when compared to the CEE. Its decline of frontier and domestic technological intensity has been much sharper than in the CEE. This loss of technology intensity of CEE has been compensated by stronger interaction with global economy through high coinvention rate which has not been the case in Russia.

China's profile of technology upgrading shows very strong increase in both domestic as well as in frontier technological intensity at the same share of high tech patents. On the other hand, technological upgrading was not followed by its increased technological openness. In this respect, a Chinese model of technology upgrading is quite different from the CEE which had to compensate its decreasing technological intensity by more technological openness.

India has very low technological intensity which despite its high economic growth in this period has further shrank questioning whether its further growth can rely on technology or on other production factors. Similar to CEE, India has to compensate much less dramatic loss of technology intensity by increase knowledge cogeneration (COINV).

Changes in **Brazilian** technology upgrading profile have been much less intensive when compared to China, Russia, and CEE. Relatively small decreases in technology intensity and in share of high tech patents have also resulted like in CEE and India to increases in knowledge cogeneration at relatively similar NAFI and FANI rates. South Africa followed similar pattern as its domestic and especially frontier technology intensity have declined as well as share of high tech patents. As in Brazil, CEE and India this has led to increases in co-invention rates and with slight changes in NAFI and FANI rates at unchanged degree of technology diversification.

Finally, considering all EU28 economies plus BRICS **we rank the countries** according to each indicator in the years 1995 and 2011. By adding ranks we calculate one rank for each of the three dimensions. The goal is to identify relative changes in the rankings for each of the countries between 1995 and 2011 in each dimension of technology upgrading.

In terms of **technology intensity**, CEE (with exception of Slovenia) are firmly among the low performers (holing positions in second half of the ranking) together with South EU. This is expected given that drivers of their growth are not related to technology but to production capability. In this dimension BRICs are not a homogenous entity. Their positions in terms of technology intensity differ widely signaling very different opportunities for growth based on technology. China has increased by far the most due to remarkable increase of both TN and resident patents.

In what concerns **structural change**, economies that are weak in terms of technology (patent) intensity show large changes in their benchmark position in terms of structural change. These results are in line with our assumption of structural change underlying technology upgrading of middle income economies towards high income. China and Estonia are again the biggest improvers in terms of ranking which is a quite important additional evidence of their technology upgrading given that China is third ranked and Estonia 17th in terms of technology (patent) intensity.

The biggest changes in terms of increased **openness** in patenting activities took place in Lithuania, Estonia, Luxemburg and Ireland while the biggest relative 'withdrawals' took place in Italy, Portugal, Slovenia, Czech R and Spain. Our data shows that 'globalizaton of technology' is not universal process but evolves very unevenly reflecting very much country specific interactions between national technology systems and external environment. Interestingly, four out of five BRICS (with exception of South Africa) have not further opened in terms of knowledge exchange in terms of patenting. This suggests that despite foreign presence in R&D in these economies, in particular China and India, this by itself has not led to relatively higher openness of their technology systems.

In overall, our analysis puts the upgrading paths of the EU28 and CEE in the context of BRICS and shows strong and weak features of the CEE technology upgrading. Our research shows clearly that paths of technology upgrading are very country specific though differences among CEECs are relatively much less present than when compared to BRICS.

CEECs are positioned relatively well in terms of technology intensity at the world technology frontier though their economic growth is not triggered by these type of technology activities. Our data indicate lower technology intensity of the CEE as economies (TN/GDP) vs. their relatively higher technology intensity as countries (TNCpc). This is an indication of mismatches in innovation systems of the CEECs especially regarding the relationships between technology activities in business and public sectors. These mismatches will need to be addressed so that the technology activities outside BES could be made more economically relevant.

Nonetheless, CEE technology upgrading as depicted by patents is within the BRIC pattern (with exception of China which in terms of technology upgrading has de facto delinked from BRICS). In the BRIC context, the CEE characterize very open innovation system with a high share of coinventions and high FANI rates but also weak organizational capabilities to commercialize its own inventions.

In terms of relative changes in technology upgrading CEE are firmly in the lower half of the EU28 list together with four out of five BRICS (except China and Slovenia). The only really big relative improver in terms of technology intensity is Estonia while other countries have recorded much less significant relative changes. Diversification of their technology profiles as proxy for technology upgrading of middle income economies is also well behind Chinese changes again with the exception of Estonia. The interaction of CEE with the global economy in terms of knowledge exchange interaction with global economy in overall is also not very strong again with exception of Lithuania and Estonia.

In overall, CEE region shows good relative position in relation to BRICs but degree of changes in technology upgrading between 1995-2011 falls within BRIC (except China) spectrum. The biggest difference compared to BRICS is much higher openness of CEE in terms of patent generation and weak control of patenting process. We interpret this as reflection of weak organizational capabilities of the CEE larger local firms. A specific position of the CEE as part of the EU has huge implications on how technology upgrading will evolve. Also, given their size, the policy approaches to technology upgrading in the CEE are and will continue to be quite different when compared to BRICs. However, the challenge to couple domestic with foreign technology efforts is much more pronounced in this region than elsewhere.

Finally, our analysis shows that technology upgrading is multidimensional construct and that aiming for aggregate composite indicator may actually mask the key issues which arise from different stages of technology upgrading in which countries find themselves and from their specific paths of technology upgrading. CEE grew during 1990s/2008 based on production, not technological capability. Their future growth will increasingly depend on building technological capabilities at world frontier level. Our analysis shows that the basis for such growth exists only to a limited extent and that speed of upgrading towards world frontier activities is well beyond required for catching up.

Equally, our analysis shows that solutions for improved technology upgrading will need to be found with their existing innovation model of small open economies integrated into the EU.

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