Title: Establishing "Green Regionalism": Environmental Technology Generation across East Asia and Beyond

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This research project advances our understanding of complex interdependence among countries. Existing research has found that total factor productivity (TFP), the residual from the economic growth function, is hindered in the absence of a country's strong political and legal institutions or if a country does not already have a sufficiently high level of TFP. We also know that regional efforts to eliminate pollution are complex. Bridging these two areas while focusing on a high polluting yet high innovating region, the following research questions are posed: Are Northeast Asian countries key collaborators in pursuit of green R&D? Are Northeast Asian countries collaborating extensively with each other? What are the implications for other regions' attempts to establish these kinds of relations? To answer the above questions, biofuels-related technology as defined in the International Patent Classification's "green inventory" of environmentally sound technologies is examined. Patent data is drawn from the USPTO and inventors' country origin as the unit of analysis. For the 1990-2013 period, the Northeast Asian countries are in the core of a small set of collaborating countries. There is evidence that their centrality has increased in recent years. Most importantly, East Asia is becoming a singular research hub in terms of biofuels-related R&D, offering a counter in the foreseeable future to the dominance of the American and European research network hubs.

I. Introduction

Cross-national coordination is intrinsically difficult, and there are special considerations when we consider coordinating environmentally-related R&D. Fewer players make it easier to address collective action concerns, and neighbors are more willing to share intellectual property because of pollution's negative externalities. We also know that environmental regional regimes are not easily created (Keohane & Victor, 2011) and that in Northeast Asia, the region of interest here, there are confounding factors such as varying levels of pollution, environmental institutions, and capacities and capabilities to deal with pollution. Nonetheless, there has been coordinated management in the region, evidenced by sufficiently funded national environmental agencies, strong regional non-governmental organizations, and a host of multilateral organizations (Solomon, 2007).

This research on international R&D collaboration and the East Asian environmental regime is fueled largely by two existing attempts to approach this issue, one offering a platform for understanding environmental regionalism in Northeast Asia while the second presents a methodology for quantifying the effects of R&D collaboration. Building on the exploratory and seminal research of Wagner and Leydesdorff (2005) and Wagner (2005), and consistent with Fankhauser et al. (2013), studied here are not only the winners of green innovation but also how such outcomes are impacted by and contribute to cross-border knowledge flows. The phenomenon of environmental coordination within Northeast Asia is explored in Shapiro (2014) where a science and technology-based epistemic community is identified. An epistemic community is defined as a group of ecologists within and across borders that can resist short-term political concerns, inform policymakers, and see beyond the narrow view of opportunity costs of environmental policies (Haas, 1990). On this basis, we would expect the technologies generated from an epistemic community to be significant, connected to ambitious but not politically-driven policies, and long-term oriented.

The methodology to quantify international R&D collaboration and its effects is consistent with Shapiro and Nugent (2012), which looks at international R&D collaboration in the form of cross-national patenting affects technical efficiency. We have no idea yet how Japan, China, Korea, and Taiwan measure up in terms of environmentally-related R&D output, so this study will focus on R&D effectiveness as it is measured by the number of patents approved in a particular country and year. The explosion of collaborative R&D presented in Shapiro and Nugent (2012) raises the expectation that environmental technology generation positively influences both technological growth and environmental conditions. We see collaboration between the world's technology leaders and other countries increasing over time as presented in Figure 1.[1] Yet, whether such effects are greater than other forms of R&D is an open question and does not fall under our purview.

Figure 1 here

Accounting for R&D output measures such as patents and publications allows us to verify firsthand whether the Northeast Asian epistemic community is undercut by a weak collaborative record or whether it is inclusive, forward looking, and resistant to political influences. The longitudinal analysis allows us to study how the epistemic community has developed over time and assess which country partnerships have the greatest impact on technological growth. In this way, we are able to speak authoritatively to both traditional and contemporary concepts of international relations and technology development.

[1] In Figure 1, the tier 1 countries are U.S., Japan, and Germany for all years. After 1990 and 1995, respectively, Taiwan and Korea joined this group. See Shapiro and Nugent (2012) for details.

II. International R&D collaboration as a political-economic concept

International R&D collaboration can yield economic growth for individual countries while simultaneously increasing global welfare through the generation of advances in science and technology which would not have been available under non-collaborating conditions, a point consistent with Barrett's (2007) discussion of global public goods. This practice reflects the internationalization of externalities which had previously been isolated to individual countries, particularly shared environmental and economic costs within regions.

There is evidence of the contribution of R&D collaboration to economic growth in general.[2] Numerous scholars, starting with Aghion & Howitt (1992), Helpman (1993), and Romer (1990), developed R&D-based endogenous growth theory as a means of explaining continuing steady growth in high income, highly capital-intensive countries for which the convergence properties of neoclassical growth theory would otherwise suggest declining growth rates over time. Attempts to extend the neo-classical model to capture R&D collaboration's effects on growth have eschewed the use of international R&D collaboration, much less R&D collaboration about environmental technologies. By incorporating international R&D collaboration into these earlier models, we deepen our understanding of the determinants of technological growth. But, by focusing on environmental technologies, we can build on the

[2] Kim (1999) investigates the important role of informal mechanisms in transferring technology to technology lagging countries when the latter are endowed with high levels of absorptive capacity; for a number of OECD countries over time, Frantzen (2002) finds that both international and domestic R&D spillovers increase TFP for large economies; Park (2004), in exploring the effects of R&D in domestic and foreign for fourteen OECD countries, Korea, Taiwan, and Singapore, identifies international R&D spillovers from foreign manufacturing research efforts by tracing trade flows and outsourcing across countries and sectors.

descriptive evidence and properly test for the presence and effects of epistemic community building.

Two institutions are of considerable relevance to R&D collaboration and for which measures are available for all countries in our sample: intellectual property rights (IPRs) and political institutions. The latter is a measure believed to assure stability in relevant policies and institutions (Henisz, 2000), thereby potentially at least having a positive effect on the willingness of agents to invest in R&D. IPRs, on the other hand, can attract technology to a country (Caselli & Coleman, 2001; Mansfield, 1995) especially after the returns to innovation resulting from such IPRs become apparent (Kim, 2003). It is worth noting that Yang and Maskus (2003) dissent from this view, claiming instead that stronger IPRs may discourage innovation and reduce international technology transfer in countries at early stages of development.

In a review of the literature, Aron (2000) also confirms that both key political institutions (in this case civil liberties) and property rights are determinants of economic growth. The conclusions, however, were probably not robust given the likelihood of simultaneity issues between institutions and growth and the fact that the measure of political institutions was perhaps not the most relevant one to patenting and R&D collaboration. Just as Barro (1998) concluded in an examination of the connection between growth and democracy that there is a nonlinear relationship between political rights and economic growth, it is appropriate to allow for threshold effects in the effects of institutions on international collaboration and total factor productivity (TFP), the growth residual.[3]

[3] Specifically, Barro (1998) demonstrated that political rights can have a positive effect on growth up to a certain threshold level of such rights but then a negative effect on growth after that threshold is reached. Feng (2005), has identified other variables intervening in the relation between democracy upon economic growth while Brunetti (1997) found political rights measures

As shown in Shapiro and Nugent (2012), there is keen international competition for researchers and research investment and that the ability of firms in a home country to take advantage of such patenting in order to raise productivity at home may be limited by insufficient endowments of relevant skills and capital and perhaps more importantly weak institutions to attract investments and enforce property rights. As well, the intensity of nationals and firms in collaborative patenting with those from the most-patenting countries has a rather consistently negative effect on TFP unless offset by the positive effects of interaction with GDP per capita or possibly the lagged level of TFP.

Another plausible explanation is that patenting may impede the ability of countries at relatively low levels of patenting, low levels of GDP per capita, and low levels of TFP to imitate and reverse engineer foreign technology. Imitation and reverse engineering have long been known as lower cost means of raising TFP for such countries than patenting (Kim, 1999). Stronger IPRs help suppress reverse engineering and imitation efforts, so they may in fact help limit the disbursement of knowledge and the growth of key capabilities. Indeed, as Maskus et al., (2005) note, this is the balancing act between protectionism and development.

While these findings are significant to the extent that they recognize and account for crucial elements of the political economy, there is no acknowledgement of the role of key actors in the entire collaborative process. Specifically referenced here is the function of researchers and the potential for multiple individuals from multiple countries to be engaged on a single research project. By shifting our focus to the phenomenon of co-inventorship in patenting, we are able to relax the assumption that multiple researchers from a single country have the same effect on international partners as one researcher. Yet, before we can understand this fully, we must update

to be less statistically significant than measures of political volatility and subjective perceptions of politics.

existing theories of international coordination in recognition of the fact that these collaborations do not occur in a vacuum.

III. Updating "complex interdependence": the Northeast Asian epistemic community

International R&D collaboration is preliminarily framed in the context of a world of "complex interdependence", as outlined by Keohane and Nye (1989). Initially, this concept represented an ideal type opposing realism, and it has been bolstered with strong evidence that it is indeed happening and that the number of areas in which international regimes plays a role has likewise increased. One must attend to these regimes, particularly their formation, effectiveness, utility, and viability.

The fundamental issue for international regimes is essentially the same as that for all international behavior: cooperation. International regimes are concerned with sustained cooperation involving "common property resources" such as security, trade, and the environment. In this discussion of international regimes, the Grotian tradition is subscribed, in line with Krasner (1982), which offers an alternative to the conventional structural approach. This rejects the assumption that the only limit to sovereign states is the balance of power. Regimes are also temporary arrangements, fluctuating with shifts in power or interests. There is a clear utility function embodying a sense of general obligation, consistent with Jervis's (1982) clear "reciprocity", which involves the sacrifice of short-term interests for the expectation of reciprocation sometime in the future. In this way, behavior infused with principles and norms is the distinguishing characteristic of regime-governed activity vis-à-vis narrow calculations of interest (Krasner, 1982).

When nations choose to forgo independent decision making, there are “dilemmas of common interests” and “dilemmas of common aversions.” These “dilemmas” dictate that, in order to reach the Pareto-optimal outcome, all players must ignore their dominant strategies. In the former case, the Pareto-optimal outcome is ensured, while in the latter it is avoided. The importance of mutual expectations cannot be understated, as the returns from involvement in an international regime are a function of all parties’ choices and actions (Stein, 1982).

Well-known configurations of international regimes have been made in terms of security (Jervis, 1982) and trade (Ruggie, 1982). More central to the discussion here, Young (1990) identifies international regimes as the solution to collective action problems, focusing solely on the mitigation of suboptimal outcomes with respect to environmental change. Environmental change, such as ozone layer depletion, global warming, and biodiversity loss, involves concerted action among states. Such action is required in the instance that individual nation-based activities create spillover effects and negative externalities for neighboring and non-neighboring states.

The establishment of the regime for protection of the ozone layer initially generated interest in the study of international environmental regimes, such as the 1985 Vienna Convention, the 1987 Montreal Protocol, and the 1990 amendments to the Montreal Protocol. Young (1990) points out that, although environmental regime formation is predominantly established in the framework of conventions and protocols, there are also cases in which environmental regimes are constituted in initial agreements, such as the 1946 International Convention for the Regulation of Whaling, and the 1973 and 1978 MARPOL Convention for the Prevention of Pollution from Ships.

In response to the preponderance of qualitative analyses of international environmental regimes, Breitmeirer et al. (2006) created a database based on the responses of experts regarding

23 environmental regimes. The main research questions in their study dealt with the process of regime creation and efficacy. These are also important, but issue may be taken with conflating case selection, the limitations in respondents, and having limited coverage of greenhouse gas emissions from 1992 to 1998. To some extent, these are addressed qualitatively by Biermann and Siebenhuner's (2009) treatment of international bureaucracies, such as the OECD, World Bank, and UNEP and Bulkeley et al.'s (2012) survey of sixty different international environmental initiatives. Notably absent from these studies is the role of international technology transfer as a component of international environmental regimes.

Haas's (1990) examination of environmental regimes emphasizes epistemic communities, which are crucial for fostering environmental regimes and coordinating policies among nations. These communities had their origins in several different (sets of) environmental treaties, which were not conducted under the leadership of a particular state but through transnational networks – epistemic communities – that are politically empowered, knowledgeable, and motivated around shared causes and beliefs. As defined by Haas, "epistemic communities are transnational networks of knowledge based communities that are both politically empowered through their claims to exercise authoritative knowledge and motivated by shared causal and principled beliefs" (Haas, 1990: 349). In this way, the established understanding of how international cooperation may be achieved shifted from recognizing a single powerful leader to recognizing a group of specialists.

A crucial factor of epistemic communities in environmental regimes is their knowledge base, and it is this point which is of greatest significance for the present study. With regard to environmental issues, for example, epistemic communities are comprised of ecologists who are able to resist short-term political concerns, inform policy makers, and see beyond the narrow view of opportunity costs of environmental policies. Currently, there is a parallel group of experts operating in conjunction with ecologists in order to counter the increasing trend of greenhouse gas emissions. While Andonova et al. (2009) and Abbott (2012) offer what is likely the closest theoretical construct to that proposed here, the claim is made here that scientists act in similar ways to other non-state actors in creating bridges across countries in order to address environmental and energy-related issues. This is presented in the structural model in Figure 2 where environmental scientists/ecologists are shown to play a central role.

Figure 2 here

To clarify the position taken in this paper, while Haas (1990) emphasizes the role of ecologists in affecting international cooperation, it is assumed here that unintended consequences may result from the influence of ecologists. Consider for example the backdrop to the 1987 Montreal Protocol as analyzed by Haas. Several studies conducted just prior to 1987 indicated that international controls on chlorofluorocarbons were necessary to protect the ozone layer. Based on this information, a transnational epistemic community of atmospheric scientists took steps to influence the positions of the UNEP and the United States. The information, however, was not necessarily certain, calling for anticipatory action (Haas, 1990). In this case, the common belief and desire of environmental protection superseded the scientific method. One may argue, however, that epistemic community building can also occur when scientists and researchers from different countries work together even when bilateral/multilateral environmental agreements are not established. Indeed, the legitimacy of researchers' political pursuits would be further bolstered when matched with scientific and other research outcomes.

Turning to the case at hand, there is such an epistemic community in Northeast Asia in which groups of ecologists cross traditional actor and state boundary lines. This is justified as there is a clear need to address environmental problems in the Northeast Asian region. China has exhibited exponential growth in the amount of carbon dioxide – a conventional proxy for all greenhouse gases – over the same period, shown in Figure 3. Such growth in carbon dioxide emissions is not unexpected given the size of China's population and its steadily increasing appetite for energy since the 1970s.

Figure 3 here

While innovation in pollution control equipment had traditionally been within the purview of the OECD countries (Lanjouw & Mody, 1996), the increase in the use and generation of environmental technologies in Northeast Asia, and China in particular, has been nothing short of remarkable. Consider, for example, the rise in the number of air pollution-related patent applications filed by China in recent years, shown in Figure 4. Consider equally the prevalence of collaboration between these countries for all co-authored science and engineering publications from 1998 to 2008, as shown in Table 1.In the context of complex interdependence and our updated understanding of epistemic community building, several research questions are considered here: Are Northeast Asian countries key collaborators in the pursuit of green R&D? Are Northeast Asian countries collaborating extensively with each other? And, what are the implications for the structural model presented in Figure 2 if Northeast Asia becomes a successful complement to the existing epistemic communities involving, separately, the United States and the European Union?

Figure 4 here

Table 1 here

IV. Methods and data

To assess dimensions of the epistemic community in Northeast Asia and answer the research questions presented above, it is necessary to analyze the connections among researchers. This necessitates study of the networks among researchers that are engaged in “green technology” generation. Network analysis is currently undergoing a surge in its application in the area of policy analysis, (Gerber et al., 2013), where actors and institutions across geographic areas are shown as likely to coordinate when they have shared characteristics. Kinne (2013), in particular, uses network analysis to confirm that international ties can be established between/among states when there are shared characteristics. This approach is wholly consistent with that outlined below. Indeed, Kinne’s attempt to examine international connections over time reveals one of the challenges faced by researchers who are interested in establishing temporal priority (and thus causality): nodes (actors) often shift sporadically in networks over time and in unpredictable ways. This is not to say that the patterns identified at different time periods are not in and of themselves interesting but that expectations about network structures are difficult to make. Nonetheless, the findings presented below show that there are major transitions occurring and that Northeast Asia has played and continues to play a key role.

The conventional method for understanding research-to-research connections is through an examination of publication co-authorship and/or whether there is co-authorship on a patent. Breschi and Catalini (2010) make a first attempt to look at these connections in their exploratory analysis of interlinks among patents and publications. For the sake of brevity, the focus in this study is limited to instances of “green” patenting only. Such patents are based on the “IPC Green Inventory” developed by the International Patent Classification (IPC) Committee of Experts in order to facilitate searches for patent information relating to so-called Environmentally Sound Technologies, including the following: alternative energy production, transportation, energy conservation, waste management, agriculture/forestry, administrative aspects, and nuclear power generation. Within each of the categories are further subdivisions. In alternative energy production, for example, are biofuels, integrated gasification combined cycle, fuel cells, pyrolysis or gasification of biomass, harnessing energy from manmade waste, hydro energy, ocean thermal energy conversion, wind energy, solar energy, geothermal energy, other production or use of heat not derived from combustion, using waste heat, and devices for producing mechanical power from muscle energy. Again, for the sake of brevity, the focus is further narrowed to biofuels-related patents, a subdivision within the alternative energy production category.

The use of patents as a measure of scientific and/or technological output is well established.[4] Along the lines of existing claims that the value of patents exceed mere "counts" (Lanjouw & Schankerman, 2004), focus is given particularly to connections between/among patents as shown in Wagner and Leydesdorff (2005) and Wagner (2005). One method to understand these connections is through spillovers as measured by patent citations. It has been shown, for example, that energy technology originates in sectors outside of energy (Nemet, 2012). Analysis of EPO patent data also shows that, with regard to the promulgation of green technology around the world, the contribution of developing countries is minimal and isolated within their respective borders (Dechezleprêtre et al., 2011; Dechezleprêtre et al., 2013).[5] However, as acknowledged by prolific users of this measure, citations are a relatively noisy signal of spillovers as many patents fail to correspond to any spillover at all (Jaffe et al., 1998;

[4] See, for example, Hall et al. (2002) and Hausman et al. (1984).
[5] Weaker intellectual property rights play a role here in mitigating these transfers (Yang & Maskus, 2001; Yang & Maskus, 2003).

Jaffe et al., 2000). To address concerns about the value of existing collaborations, only patents that have undergone both the patent application and approval process are considered here.

Data were collected from the United States Patent and Trademark Office (USPTO) using an array of tools from Loet Leydesdorff's website.[6] As noted, the search parameter was limited to biofuels, including both solid fuels (including torrefaction of biomass) and liquid fuels (including vegetable oils, biodiesel, bioethanol, biogas, and liquid fuels from genetically engineered organisms).[7] The time parameters were limited to 1990-2013 as it was primarily after 1990 that biofuels-related R&D escalated worldwide. The unit of analysis was inventors – the country of inventor, that is – with a total of 129,640 instances listed. Based on the assumption that any collaboration at all is valued, the proportionate share of patent inventorship for each country as well as the number of inventors on each patent was not used as a weighting mechanism. In other words, the 242,331 co-inventor nodes represent the sum of all patents' Cartesian products for each patent's inventor pairings. The country breakdown is presented in Figure 5.

Figure 5 here

V. Results

The results of co-inventor pairs are generated using NodeXL.[8] For all network analysis figures (Figures 6 to 12), the Fruchterman-Reingold force-directed algorithm is used to produce the layout. For those network graphs that determine groups within the data (Figures 10 to 12 only), the vertices were grouped by cluster using the Clauset-Newman-Moore cluster algorithm.

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[6] See in particular uspto1.exe, uspto2.exe, and patref3.exe, all of which can be found at http://www.leydesdorff.net/software/uspatents/.
[7] See http://www.wipo.int/classifications/ipc/en/est/ for the exact IPC codes.
[8] See http://nodexl.codeplex.com/ for details.

Edge widths are based on edge weight values. For those graphs capturing groups (Figures 10 to 12), edge opacities are based on edge weight values. Within-country collaborations are represented by self-loops.

To recapitulate, are Northeast Asian countries key collaborators in biofuels-related patent generation? Presented for all years in Figure 6 and longitudinally for Figures 7, 8, and 9, the Northeast Asian countries have moved into the core of what is a tight set of collaborating countries. For the entire time period under analysis (Figure 6), there are approximately 25 countries that fall into this core, and there are two or three peripheral levels. Longitudinal analysis shows that there is a process of moving from outside the core to the inner core of centralized collaborators. We also observe that the countries that are already in the core become more tightly embedded in the core of collaborators.

Figure 6 here

Figure 7 here

Figure 8 here

Figure 9 here

Longitudinal effects are also present when assessing our second research question, i.e., whether Northeast Asia is a singular research hub. In the initial time period, 1990-1997, Korea, China, and Taiwan were clustered with the U.S. in a group separate from Japan, which was clustered primarily with Germany, Switzerland, Belgium, and Spain. This is presented in Figure 10 (red circles identify the Northeast Asian countries). As time passed, and represented in Figure 11 for 1998-2004, China and Japan were clustered together, while Taiwan and Korea were positioned in immediately proximate groups. Finally, in the latest period under analysis, presented in Figure 12 for the 2005-2013 period, we see continued polarization among instances of co-inventorship where the Western European countries are clustered primarily in the top-left group, the U.S. and its affiliates are clustered in the bottom-left, and the remaining countries are dispersed across the five remaining groups. While it is obvious that Germany (DE) is the key collaborator among countries beyond the left-hand side groups, inventors from Japan and Korea are working with a host of countries. We can also observe a horizontal thinning out of the biofuels-related patent co-inventorship network where it appears as though Japan, Korea, Taiwan, and China are likely to continue to move in a coordinated fashion into the foreseeable future.

Figure 10 here

Figure 11 here

Figure 12 here

While the aforementioned results provide strong evidence that the Northeast Asian countries are on the path to becoming a cohesive R&D block, they also show that there still remains no singular research hub for green R&D, or at least green R&D as measured by biofuels-related patents. This is ideal, but it could indicate that the model of complex interdependence tempered by epistemic community building continues but with a different unit of analysis and a smaller number of units; i.e., countries are replaced by their affiliated research hubs. I would argue that this is still an improvement on the failed attempts at collective action which have preceded. On the other hand, the loose grouping of several hubs on the right-hand side of Figure 12 exhibits many more connections to non-OECD countries relative to the two hubs on the left-hand side of the figure. With Germany (DE), Japan, China, Korea, and Taiwan are reaching out to the developing world more and thus quite likely represent the future of technology transfer and opportunities for total factor productivity growth.

VI. Conclusion

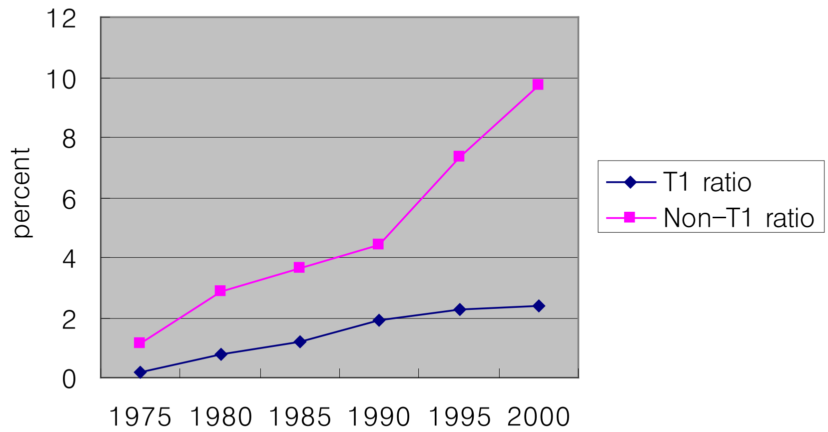
This paper has shown that epistemic community building is occurring in novel ways but in an incremental fashion for the Northeast Asian countries. We observe that Northeast Asian countries are key collaborators in the pursuit of green R&D as measured by biofuels-related patents, but we also note that they are collaborating more with countries outside the region than within the region. Yet, the pattern is toward greater intra-regional coordination and, based on the assumption that any collaboration is beneficial, there are both intra- as well as extra-regional effects. For example, such collaboration creates a path for future, ever-increasing collaborations. More importantly, and this is perhaps the most significant implication of this study, the effect of successful Northeast Asian regionalism in the wake of a previously dominant Western R&D-oriented regime indicates that Northeast Asia is on track to counterbalance the hegemony of American- and European-centered networks. This is certainly consistent with existing research that shows that North America and Europe no longer dominate collaboration and patenting.

Methodologically, it remains problematic to connect the findings presented above with other variables of the structural model presented in Figure 2. We observe, for example, that there is change over time, but we do not integrate these longitudinal effects into the broader issue of science and technologically-related outcomes possibly occuring on a much different timetable than outcomes related to legal institutions and FDI flows. One can assume that, with more data, these effects and connections will be made more transparent. One can also assume that the incorporation of a key outcome variable, pollution for example, can be a benchmark to which these seemingly disparate variables can be bound. Whatever the case, future research on this subject must acknowledge this potential scaling problem.

Theoretically, the contribution offered here to the concept of epistemic community building is at best preliminary but at least representative of the kinds of research efforts that must be taken henceforth. The results presented above are compelling evidence of the increased connections across more countries over time and of Northeast Asia's key role in worldwide collaboration in biofuels-related patenting; yet, it is too technology deterministic to claim that collaborations are interesting in and of themselves. Future research must account for the propensity of bilateral and/or multilateral environmental agreements or other incentivization mechanisms. This would allow us to examine why key actors – public or private – coordinate and interact. In Northeast Asia, scientists and engineers are fostering ties with likeminded individuals in neighboring countries, but the nature of these connections has yet to be examined – e.g., whether individuals at Chinese firms are working with Japanese university-based scientists or vice versa – and it is a crucial next step in providing a deeper understanding about how epistemic community building occurs.

Figures and Tables

Figure 1 Percentage of total patents represented by collaboration with researchers or firms in different countries



Source: USPTO (2008).
Note: “T1” represents tier 1 countries, and “Non-T1” is all other countries.

Figure 2 Accounting for epistemic community building

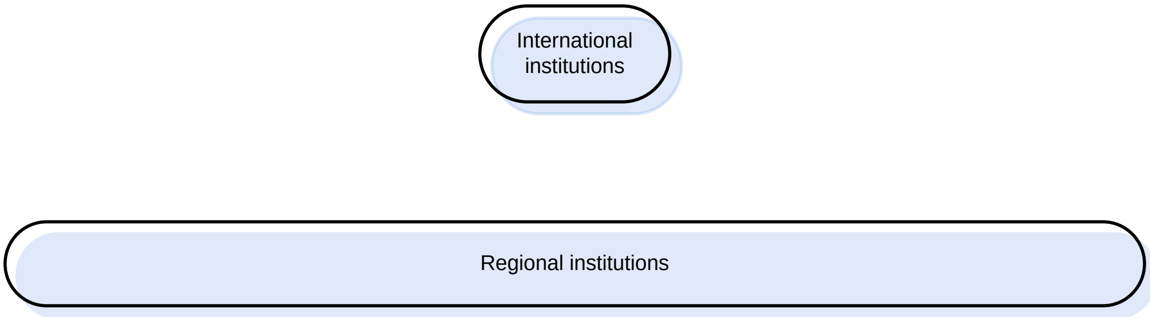
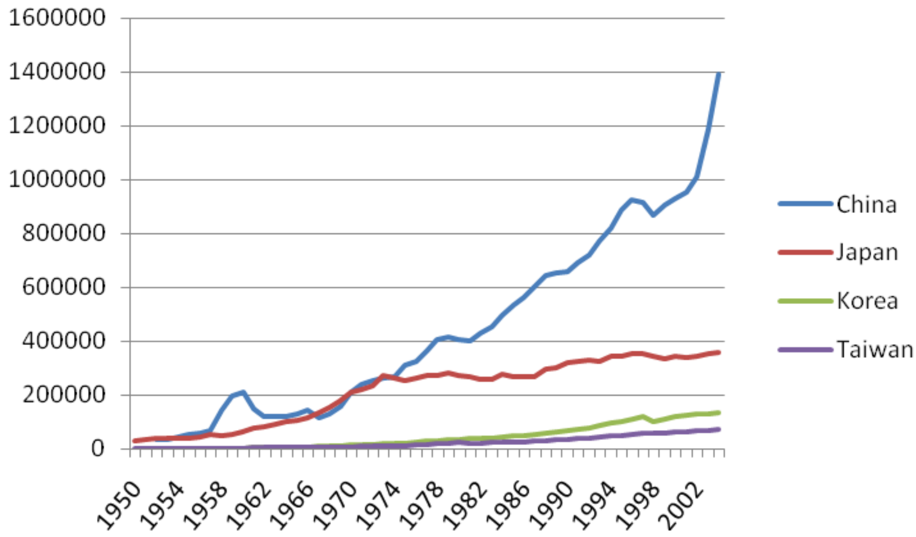
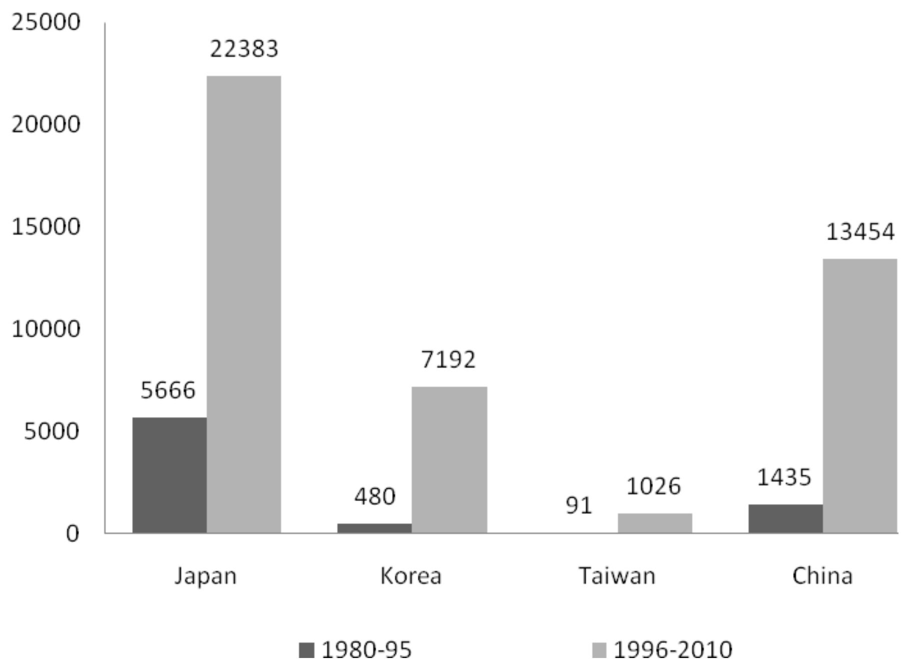


Figure 3 CO_2 emissions (mt) in Northeast Asia



Source: OECD (2009).

Figure 4 Total number of air pollution-related patent applications, by state



Source: European Patent Office database (http://worldwide.espacenet.com/advancedSearch?locale=en_EP).

Table 1 Indexes of internationally co-authored S&E articles, by selected state pairs: 1998 and 2008

Partner rank	1998 Japan	2008 Japan	1998 Korea	2008 Korea	1998 Taiwan	2008 Taiwan	1998 China	2008 China
1st	Korea	Korea	Taiwan	India	Singapore	India	Singapore	Singapore
2nd	China	Taiwan	Japan	Japan	China	China	Taiwan	Taiwan
3rd	Taiwan	China	China	Taiwan	Korea	Singapore	Korea	Japan
4th	US	India	India	US	India	Japan	Japan	Korea
5th	India	Russia	US	China	US	Korea	Australia	Australia

Source: Thomson Reuters, Science Citation Index (SCI) and Social Science Citation Index (SSCI), from National Science Foundation (2010).
Note: Article counts from SCI and SSCI based on institutional addresses listed on article.

Figure 5 Inventorship distribution by country for biofuels-related patents

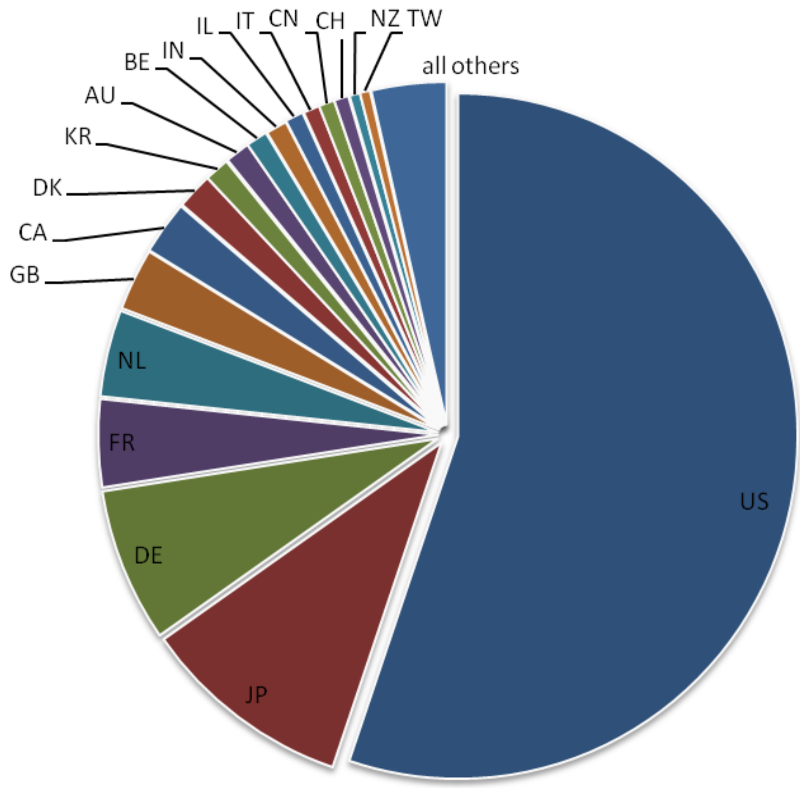


Figure 6 Collaborative patents by partner and highlighting centrality: 1990-2013

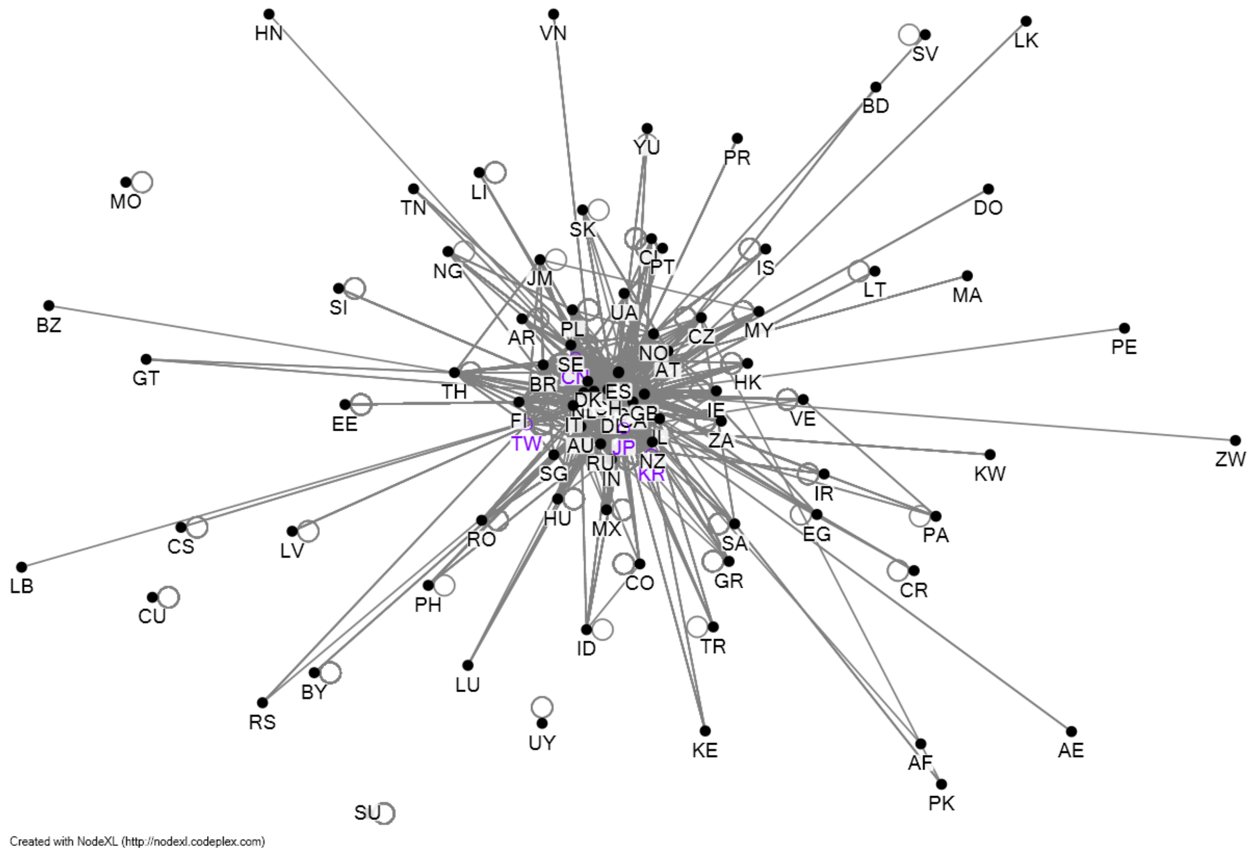


Figure 7 Collaborative patents by partner and highlighting centrality: 1990-1997

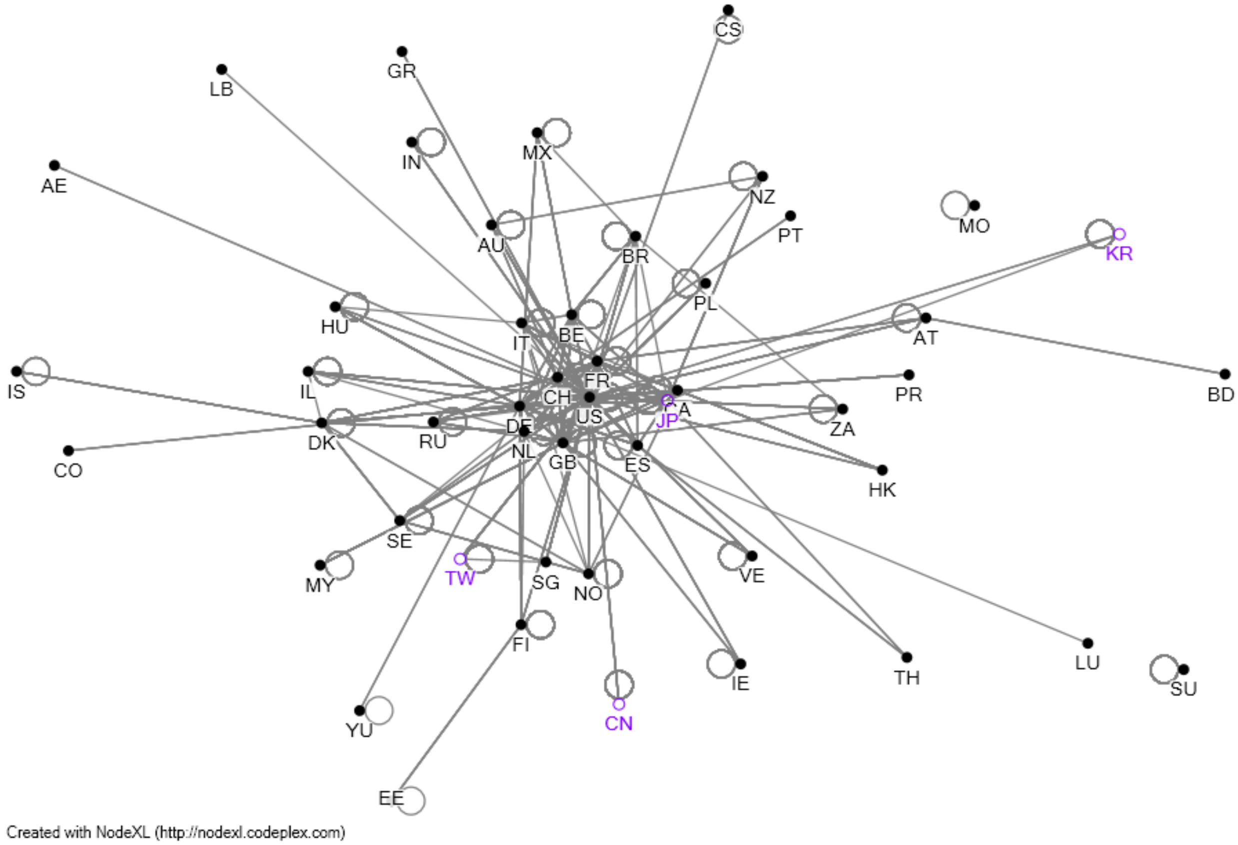


Figure 8 Collaborative patents by partner and highlighting centrality: 1998-2004

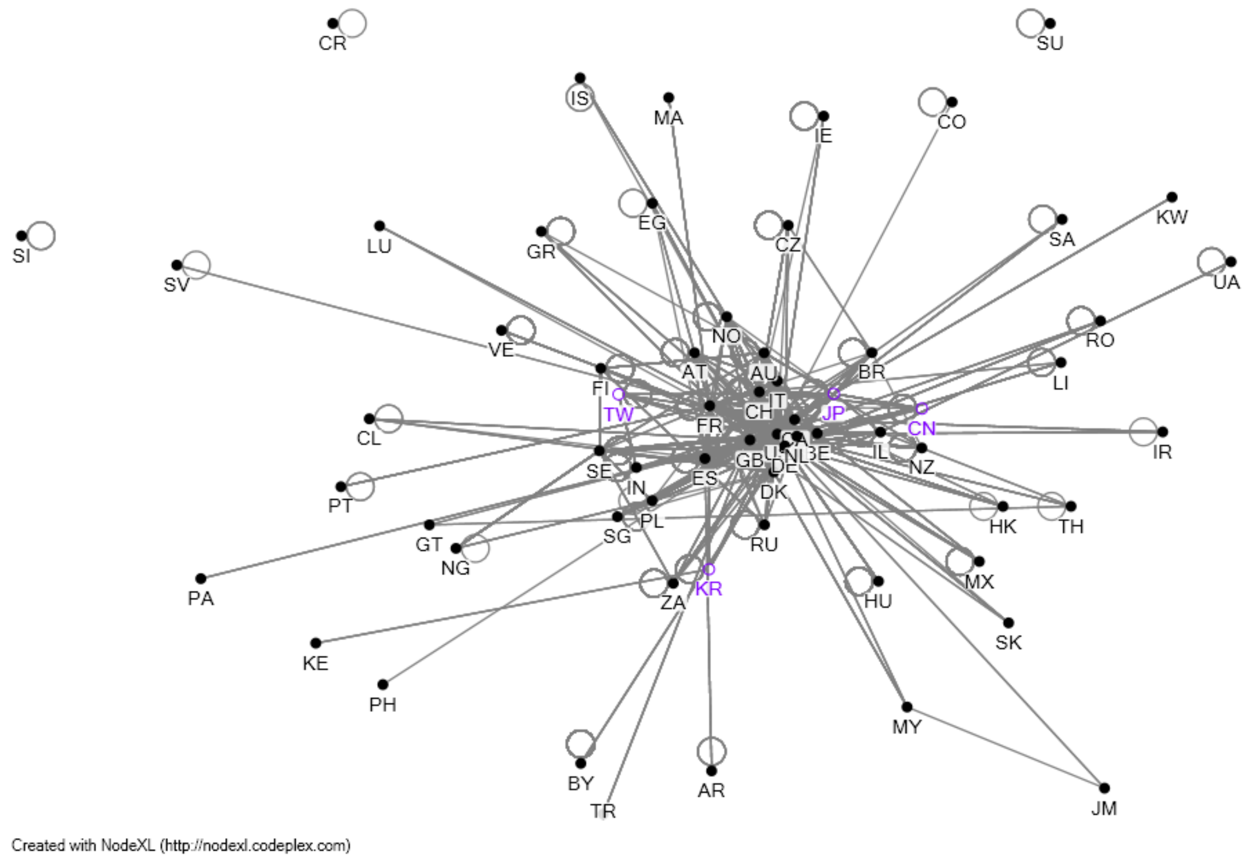


Figure 9 Collaborative patents by partner and highlighting centrality: 2005-2013

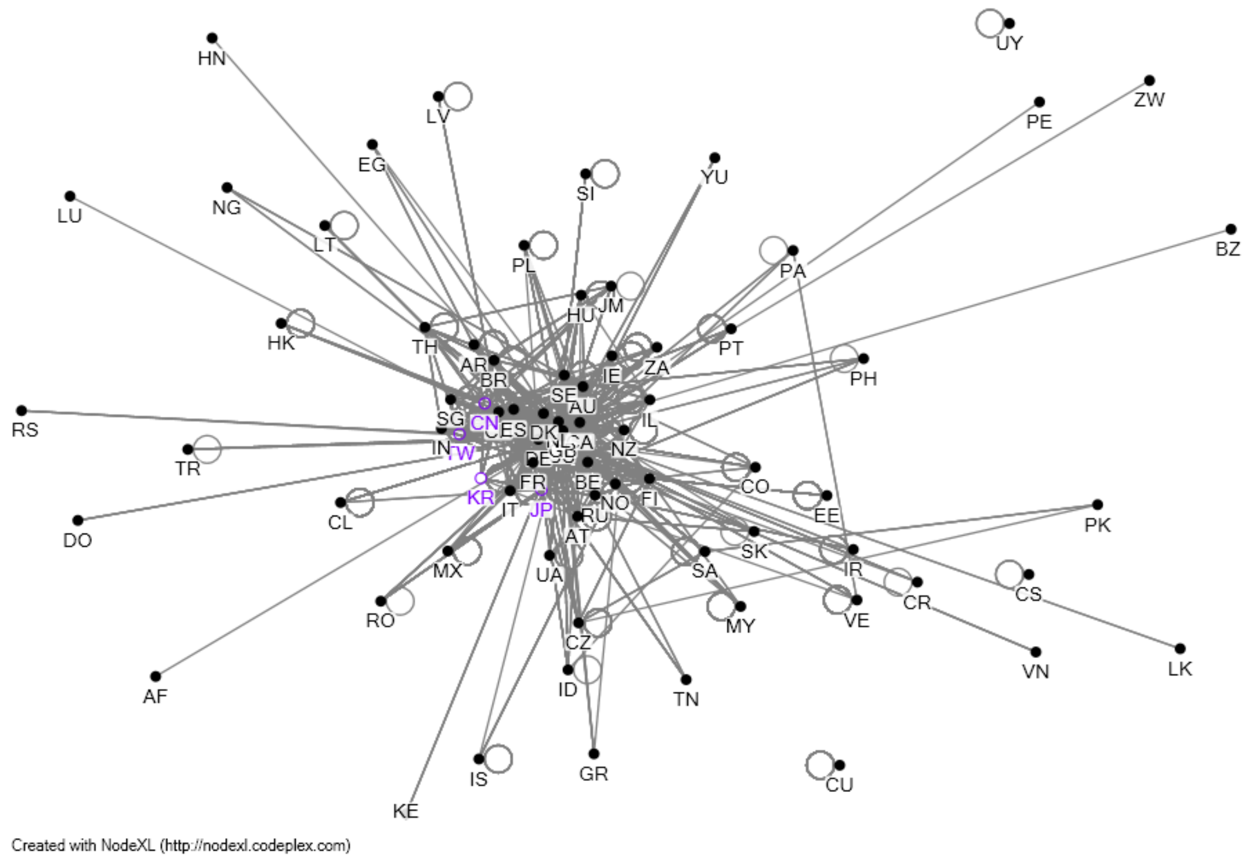


Figure 10 Collaborative patenting with sub-groups: 1990-1997

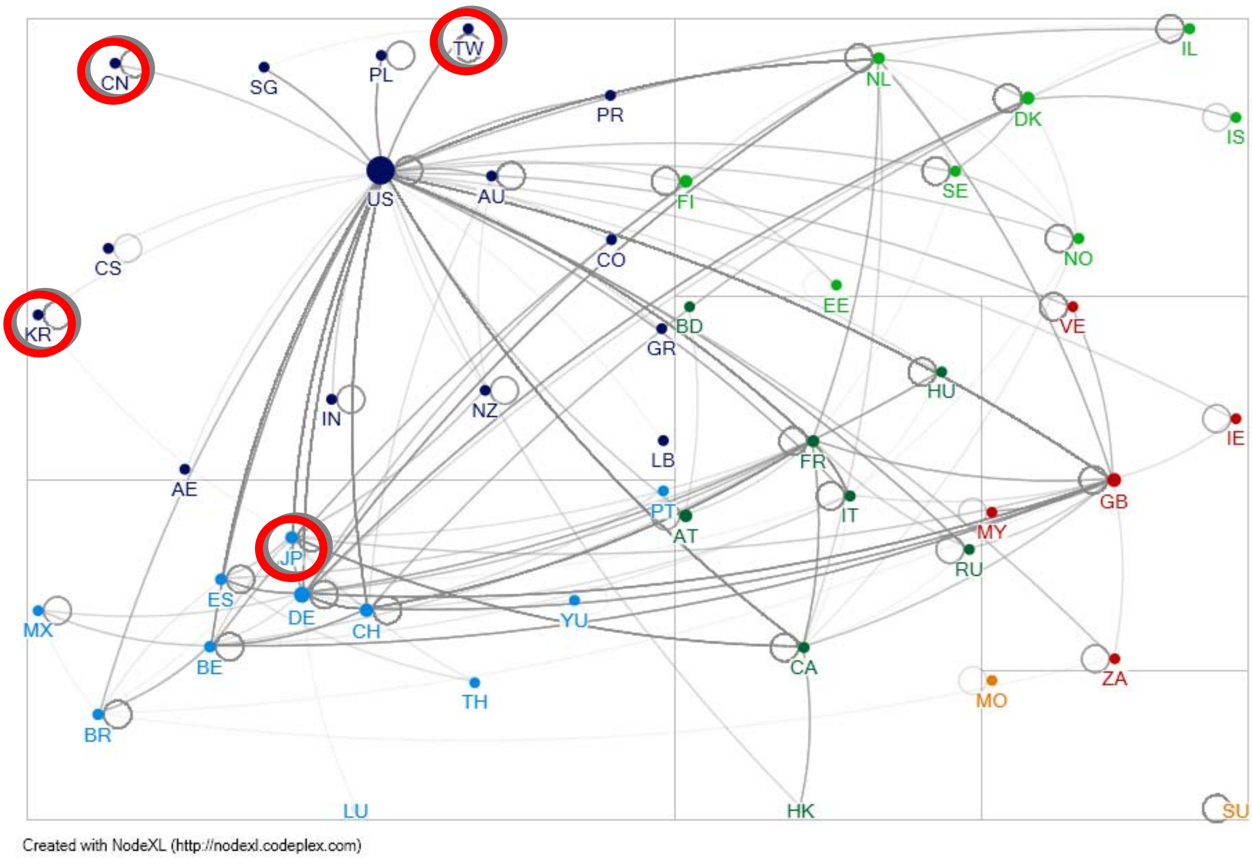


Figure 11 Collaborative patenting with sub-groups: 1998-2004

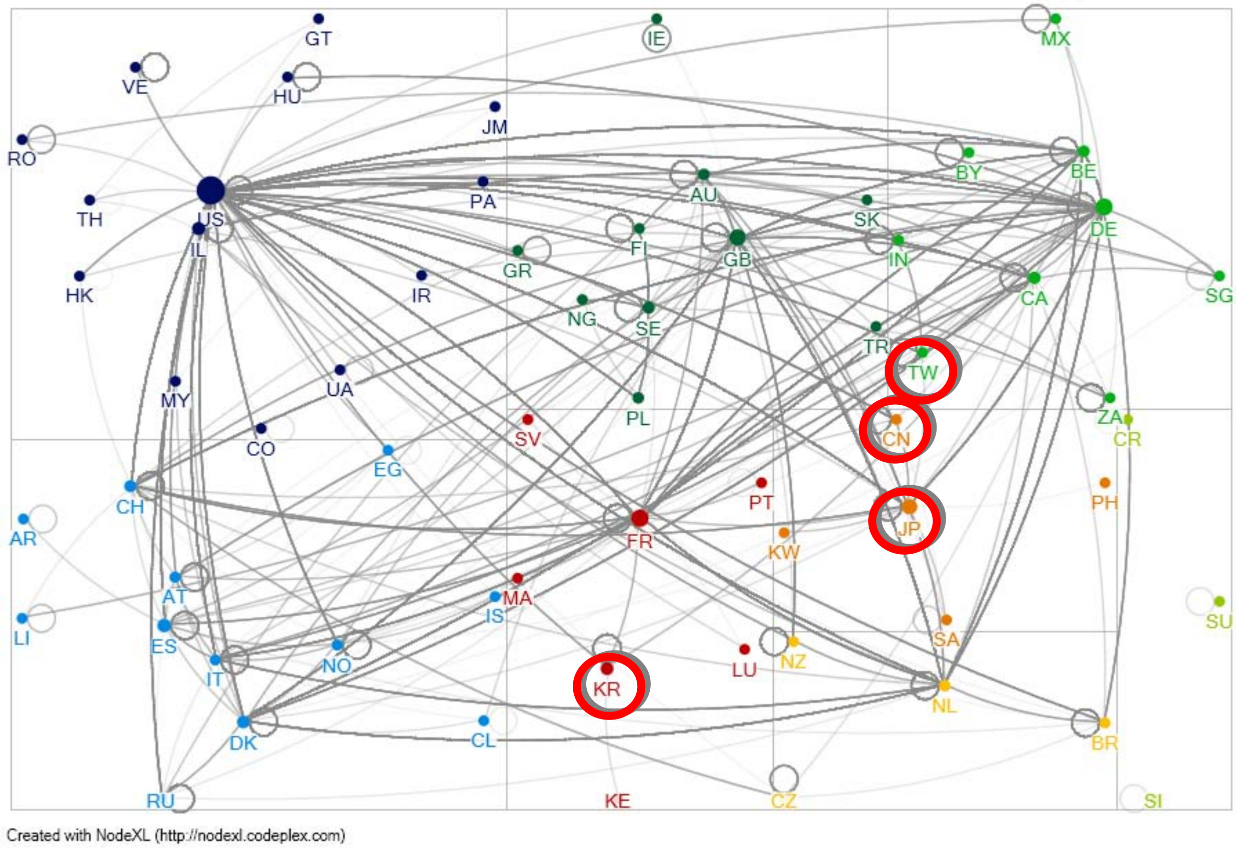
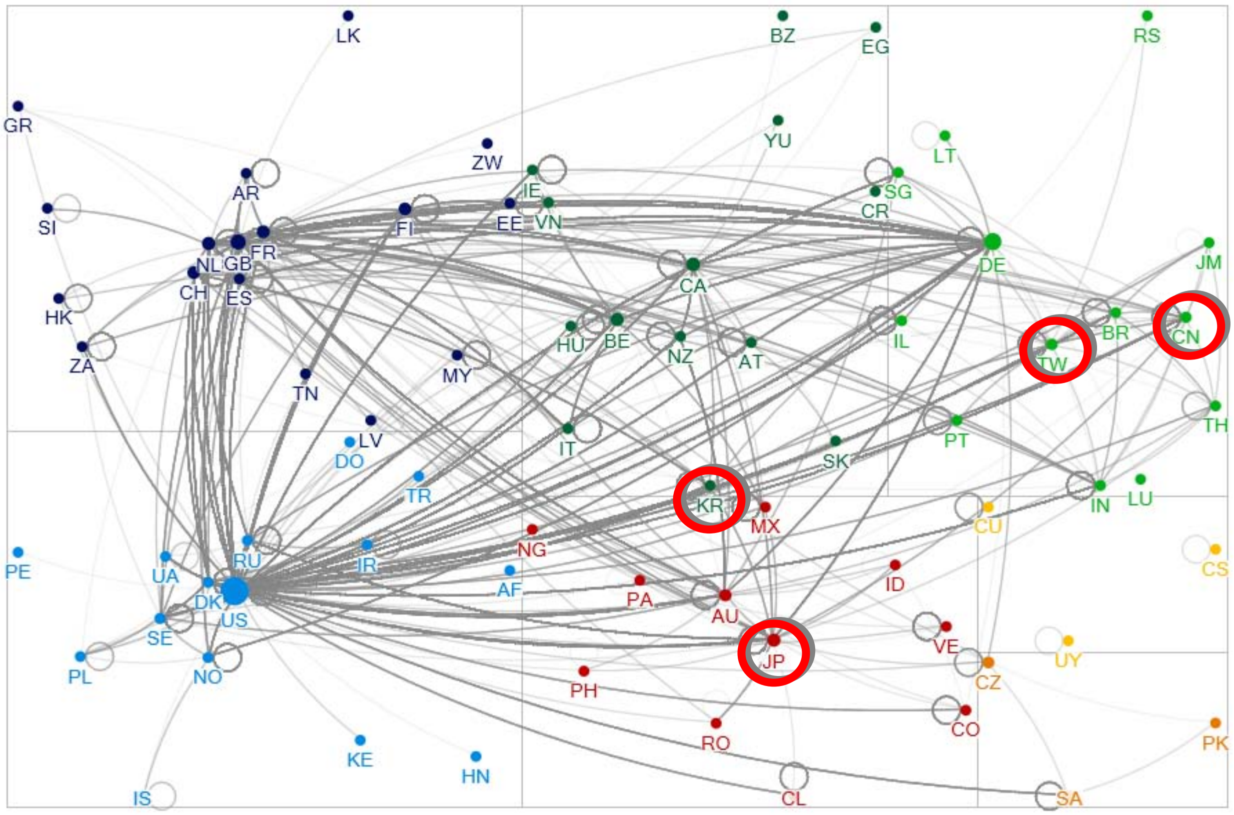


Figure 12 Collaborative patenting with sub-groups: 2005-2013



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