Subtheme: S3.6 Regional Innovation Ecosystems

Title: Regional Development in South Korea: Accounting for Research Area in Centrality and Networks

Authors: Matthew A. Shapiro, Min-Ho So, Young-Long Kim, Han Woo Park (Corresponding author)

First-author Bio: Matthew A. Shapiro is Assistant Professor of Political Science at the Illinois Institute of Technology's Department of Social Sciences. His interests include science, technology, energy, and environmental policies, particularly in Northeast Asia. He has written several journal articles and book chapters on public-private R&D collaboration in the region, and he is currently working on a study of domestic and transnational environmental interest groups in Japan, Korea, Taiwan, and China.

Keywords: Network analysis; Korean NIS; centrality; density; fragmentation

Abstract
This paper provides a first-ever look at differences of centrality scores (i.e., networks) over time and across research specializations in Korea. This is a much needed development, given the variance which is effectively ignored when Science Citation Index (SCI) publications are aggregated. Three quantitative tests are provided – OLS, two sample t-tests, and unit-root tests – to establish the patterns of centrality scores across Korea over time. The unit-root test is particularly important, as it helps identify patterns of convergence in each region's centrality scores. For all other geographic regions besides Seoul, Gyeonggi, and Daejeon, there appears to be little promise – at least in the immediate future – of being network hubs. For these top three regions, though, there is a pattern of convergence in three-quarters of all research specializations, which we attribute in part to policies in the mid- and late-1990s.

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I. Introduction

The rapid technological development of South Korea (hereafter Korea) has been well documented, but there has been little rigorous data analysis of collaboration and scientific co-authorship among South Korean researchers. Indeed, we have identified only one research attempt which showed that the national innovation system (NIS) of Korea continues to exhibit growth, but at the expense of Seoul's research brokership for the entire country (Shapiro, et al., 2010). It is still not entirely clear how and to what degree Seoul continues to dominate in terms of its research leadership, and we hypothesize that growth of regional innovation ecosystems beyond the capital is a function of two key variables: networks between such regional innovation systems and policies which focus on particular research areas but also emphasize equalization across regions. The Seoul "macrocluster" (Kim, 2010; Sohn and Kenney, 2007) has dominated less over time, but an extensive analysis of co-authorship will provide a more complete explanation for Seoul's waning dominance and the growth of research output and collaboration in other regions and cities.

Earlier studies have examined how the regional level has been important in fostering innovation through university-industry-government level – "triple helix" – relations (Cooke and Leydesdorff, 2006), as such relations are the core of knowledge-based innovation, stimulating ideas across institutional boundaries (Etzkowitz, 2008). What is most interesting, and what is the basis for a detailed study of such a research-concentrated country like Korea is that R&D collaboration in general is correlated with decentralization (Surowiecki, 2005). Formal tests of this, however, have been limited to research on decentralization and research concentration for Korea (Shapiro, et al, 2010), China and Taiwan (Chang and Shih, 2005), and Taiwan by itself (Liu and Chen, 2003). To deal with this vacuum in the literature, we employ a comprehensive methodology to a unique dataset. Such methods can inevitably be applied to other countries experiencing issues with research decentralization.

The main dependent variable – centrality of research efforts – is a measure of networks and research output. In the context of a Seoul "macrocluster", which is responsible for the dominant share of networked research output, there exists the possibility that there may be some sort of catch-up effect with neighboring regions, particularly if they have partnered with Seoul. In this way, this paper references the discussion in the economics literature on income convergence across countries, such as Hirshman (1958), but we focus on lagging research efforts within the Korean NIS. In this context, even if R&D collaboration is not correlated with decentralization, countering Surowiecki (2005), there is still a possibility for catch-up to occur through collaboration with the leading region. In line with Hirshman (1958), the center or hub – Seoul, in this case – will eventually integrate the surrounding regions through outsourcing. These dynamics become even more apparent when breaking down research sectors into specializations. In Korea, such an understanding is absolutely critical to explain why research hubs exist, how they have developed over time, and what potential there is for a dissemination of centrality in the future.

Using the most reliable longitudinal citation data available, sixteen geographic areas are the units of analysis for this paper: Seoul, six additional cities, and nine provinces. Journal article data used for this research are drawn from the Science Citation Index (SCI) database Web of Science, and we have collected and classified all journal articles published by residents in Korea according to the authors' city and/or province. Relations are classified by the numbers of journal articles coauthored by researchers in different cities and provinces. The number of ISI-listed journal articles coauthored by researchers located in two or more different provinces allows us to scrutinize patterns of collaboration within and between Korean regions. Such collaborative efforts are assumed to feed innovation in ways that are consistent with the triple helix paradigm and knowledge-based innovation across boundaries.

We use social network analysis to establish networks between regional innovation systems. We also incorporate a normalized measure of degree centrality, given wide variance among Korea's research centers. Given the paucity of research on this subject for the Korean case, we approach networks at both exploratory and explanatory levels, looking first for identifiable trends across research specializations and then for reasons why such patterns exist. The following twenty ISI subject categories are the basis for cross-specialization analysis: agricultural sciences, biology and biochemistry, chemistry, clinical medicine, computer science, engineering, environment/ecology, geosciences, immunology, materials science, mathematics, microbiology, molecular biology and genetics, neuroscience and behavior, pharmacology and toxicology, physics, plants and animal science, psychiatry/psychology, social sciences (general), and space science.

Within each region, each research area is assessed in terms of centrality degree as well as a scale-dependent normalized degree. To provide the reader with an idea of what has happened over time in Korea at the research aggregate level, the ten most-networked regions are presented in Fig. 1. On the basis of such normalized degrees, Seoul, Gyeonggi Province (henceforth Gyeonggi), and Daejeon represent more than half of all centrality in the country when research areas are taken in aggregate. This has not always been the case, particularly in the pre-1994 period, but it certainly is the case in the most recent years. As such, we focus on all sixteen regions when addressing the pre-1994 period, but we focus explicitly on Seoul, Gyeonggi, and Daejeon when examining all other time ranges.

Fig. 1 here

We test three hypotheses. First, networks and specialization are a positive function of time. There are a number of plausible explanations for stronger networks to lead to increased specialization over time. Certain geographies may share expertise based on local industrial focus, or increased specialization in one region could very well lead to more networks with other regions and experts are identified geographically. Given these preliminary explanations, this hypothesis is exploratory but nonetheless testable.

The second hypothesis builds on the first hypothesis, claiming that strong networks are concentrated around single rather than multiple regions. To clarify, while the first hypothesis explores those instances in which networks and research specialization increase over time, the second hypothesis tests for cases in which only a single region is the network hub; i.e., all other regions lack network hub characteristics. Such single-hub characteristics have been the recognized pattern in Korea until recently (Shapiro, et al., 2010), but this hypothesis has never been explored quantitatively.

The third hypothesis makes predictions about government policies and is yet again a variant of the previous hypothesis: Korea’s “equalization policy” has led to convergence in degree centrality among geographic areas. Any sort of convergence would constitute a rejection of the second hypothesis. Here, however, we pay particular attention to differences across specialization and explore time trends for Seoul, Gyeonggi, and Daejeon to identify convergence in these regions’ networks. The focus on specific research specializations allows us to comment on policies affecting the NIS which may have lessened the gap between the hub-like qualities Seoul and those of Gyeonggi and Daejeon.

The convergence hypothesis is potentially explained by a number of policy-related factors over the last forty years. Shown in Table 1, specific government interventions and structural events, such as the 1997-98 financial crisis, can facilitate regional innovation system generation. There have been multiple attempts to explain development of the NIS in Korea through publication output (Kim, 2005; Kwon, 2009; Park & Leydesdorff, 2008, 2010; Yang, et al., 2010), but it has never been done with regard to centrality scores or collaboration between regions. This is entirely appropriate, given the preliminary evidence present in Fig. 1 which confirms that time trends are present, and that regional innovation could be intensified around structural events. As such, we narrow our focus on the 1997-98 financial crisis in order to understand the effects of this shift before and immediately afterwards.

Table 1 here

We selected the early 1980s as the starting point for our data because it was the origin of Korea's NIS-bolstering attempts, part and parcel of which is the generation of research clusters beyond Seoul. From that time, government research institutes (GRIs) were restructured to deal with industrial deepening efforts. This was designed primarily to counter the distorted market mechanism which resulted from the previous Heavy and Chemical Industrialization drive. Tax credits were offered to firms for engaging in R&D efforts. Also around this time, National R&D Programs (NRDP) were established to allow universities and firms to participate in government R&D programs and compete against GRIs. One key example of an NRDP, particularly in the context of this discussion, is the creation of Daeduk Science Town in Daejeon. W. Lee (2000) claims that this was a failure because it did not generate cooperation among GRIs. The evidence presented in this paper shows otherwise: Daejeon has become one of the most networked regions in Korea.

In 1993, R&D networks were emphasized at an institutional level with the Cooperative R&D Promotion Law, which provided the legal basis to prioritize the funding of cooperative R&D. Around this time, both the Ministry of Science and Technology (MOST) and the Ministry of Education (MOE) initiated programs to suppose university-based research and research-oriented universities. These efforts had dramatic effects and reversed the declining pattern of networks, as shown in Fig. 1. Following the application of the Brain Korea 21 (BK21) project in

1998, which increased the universities' capacity to research with higher government subsidies, there has been a consistent effort to focus on bolstered innovation capacities across the country. The 2008 launching of the Ministry of Education, Science and Technology (MEST) and the Ministry of Knowledge Economy (MKE) represents the latest attempt. These policy-related events and their details, presented in Table 1, will be referenced repeatedly in the following analysis.

The remaining sections of the paper are designed to address these three hypotheses and present the reader with details about this unique dataset of centrality scores and research specialization. To these ends, Section II outlines the data and the methods employed, Section III presents the results from the empirical tests of the hypotheses mentioned above, and Section IV provides a concluding statement and policy prescriptions.

II. Data & Methodology

Calculation of the centrality score is done through a conventional method of measuring the degree of networks. Social network methods deal with an S_{ij} matrix where i and j are nodes and the value between i and j represents their internal relations. Wasserman and Faust (1994) explain that there can be various node types in this network analysis, such as people, subgroups, organizations, or collectives/aggregates like Korean cities and provinces, both of which are the node types considered here. Relations are specific substantive connections between a set of nodes, and one or more types of relations can be measured for a single set of nodes, enabling an analysis of centrality, as well as density and fragmentation, among Korean geographic regions. Tie data converted into a matrix in VNA format and graphic presentations using NetDraw reveal networks particularly between Seoul and Gyeonggi, Seoul and Daejeon, and, to a lesser degree, Gyeonggi and Daejeon.[1]

The first hypothesis – networks and specialization are positively correlated over time – is tested through an analysis of centrality scores. Our claim is that increases in centrality scores indicate greater networks, and that this pattern is revealed through an analysis of time trends. Our inclusion of a dummy variable for region at this stage is important in building up the remaining two hypotheses, which focus expressly on cross-regional differences. This also represents our only attempt to look for patterns across the entire geography of Korea, as we code for four

[1] These figures are available upon request to the corresponding author.

categories of geographic regions: Seoul, Gyeonggi, Daejeon, and a non-top-three region category. We also examine the possibility that year and region could have a combined effect on centrality scores.

A simple correlation matrix does not suffice in identifying statistically significant and positive relationships between centrality of research specialization and time, and it would certainly rule out any sort of multivariate analysis. We opt for OLS and log-transform the dependent variable, given its non-normal distribution. This effectively eliminates the entire pre-centrality period (and a few years after centrality began which had no collaboration). One technique for dealing with large numbers of zeroes in count data for the dependent variable is to use a count data-specific modeling techniques, such as Poisson. Unfortunately, while centrality measures are ultimately based on count data (i.e., numbers of publications which have been done collaboratively between regions), the centrality score itself cannot be considered a count variable.[2]

The second hypothesis – single-hub presence – is tested through an analysis of significant differences in centrality scores between the highest scoring region and the remaining regions. When significant differences are not present, we accept the second hypothesis. The test for a single-hub, building upon Shapiro, et al. (2010), is essentially a series of two sample t-tests between Seoul, which is the single region with the highest centrality scores, and the remaining twelve regions. Based on the contents of Fig. 1, it is expected that only Gyeonggi and Daejeon have any chance of catching up with Seoul and rejecting the sing-hub hypothesis.

This expectation is based on observations about the latter period of our dataset, necessitating comparisons over time. We subdivide the dataset into two periods: 1981 to 1993 and 1994 to 2009. These two periods have been selected for two reasons. For nearly every region, 1994 represented a turning point in centrality scores, which we attribute to the 1993 Cooperative R&D Promotion Law. As shown in Fig. 1, 1994 was preceded by a rather dynamic period of peaks and valleys but was followed by a period of relatively stable change. The post-1994 period also represents the time in which Gyeonggi's centrality scores rose in a previously unparalleled fashion, while all other regions experienced little change. That being the case, the

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[2] Centrality scores are also continuous, which rules out the use of a Poisson model on technical grounds.

pre-1994 period is important as a means of understanding the era in which the centrality scores of Daejeon and Gyeonggi were relatively the same as Korea's remaining thirteen regions.

The third hypothesis – convergence among regions resulting from policies – examines trends among the dominating network hubs. When testing for convergence, there are at least two options for us, both of which are couched in the economics literature. We can look at convergence in terms of whether regions achieve steady-state levels or whether regions are catching up to a leading nation (Young, et al., 2008). The former is inconsistent with our hypothesis, while the latter – for the economics-based studies – typically uses income data in which $t = 0$ is a point in time of great disparity among regions. In our dataset, the initial time period (1981) presents nearly the same centrality score for all three regions. We have opted instead, thus, to conduct a unit-root test for convergence, in line with Evans and Karras (1996), Bernard and Durlauf (1996), and Lee, et al. (1997). This test, based on assumptions of stationarity, will be done across specializations and time for Seoul, Gyeonggi, and Daejeon. These three regions were the only ones selected because the remaining thirteen are not even close to convergence, based on our observations of Fig. 1.

III. Findings

Table 2 presents the results for the first hypothesis, with the aggregated data ("All SCI") as the baseline. For ease of interpretation, we have converted the OLS coefficients into percentage form, consistent with the use of log-transformed dependent variables. For nearly every specialization, there is a consistent, increasing, and statistically significant centrality trend over time. The exceptions are the specializations of neuroscience, psychiatry, and the social sciences. There are, however, differences in terms of the effects of such year-on-year changes on each specialization: the greatest average effects of time on each specialization occur in pharmacology, mathematics, geosciences, materials science, and environment. Among those results which are statistically significant, those specializations which are least affected by time are clinical medicine, computer science, chemistry, immunology, and physics. Nevertheless, even for clinical medicine, each additional year amounts to an increase of centralization by 2.15 percent.

Table 2 here

These differences are significant across regions, with the non-top-three group typically dominating over Seoul, Gyeonggi, and Daejeon, especially from the early 1990s. This was expected, given that the aggregated centrality scores of the non-top-three regions is greater than those of Seoul, Gyeonggi, and Daejeon. Coefficients for the region dummy variable represent the difference in the expected geometric means of the log of centrality between the four groups. According to Table 2, mathematics represents the greatest difference, followed by environmental sciences, agriculture, physics, and molecular biology. Still, not all specializations exhibit statistically significant differences across regions. Differences in the geographic means of the log of centrality between the four groups were insignificant for immunology, geosciences, social sciences, space sciences, psychiatry, clinical medicine, and neuroscience.

Two final points can be made with regard to the results from the test of changes in networks and specialization over time. First, we have not presented the OLS results from the model which include a year-region interaction term. The coefficients for these interaction terms were consistently insignificant,[3] indicating that the temporal and geographic effects individually but not jointly predict centrality scores. Second, differences between regions become starker when we exclude the non-top-three group.[4] Methodologically, exclusion of the non-top-three group might eliminate the bias created from aggregating thirteen regions. It also ignores the effects of policies to equalize research across the NIS but, as Fig. 1 shows, aggregated centrality scores for these thirteen trailing regions reveal no hint of change. Even Gwangju, which should some promise in the mid-1990s, has joined the rest of the non-top-three group.

With regard to the second hypothesis which tests for a single-hub, as expected, two sample t-tests (not presented here) confirm that Seoul is far and away the single-hub, measured by statistically significant, larger centrality score means. Note that this analysis was limited to aggregated centrality scores rather than scores for each research specializations. While there might be cross-specialization differences, we felt that – at this stage – the analysis of aggregated centrality scores is sufficient to establish Seoul's single-hub status and build on the previous literature of research networks in Korea.

[3] These results are available upon request to the first author.
[4] These results (from models which omit the non-top-three group) were not included in Table 2.

Because Seoul's margin of dominance is so great, we look more closely at hubs in terms of the second- and third-highest centrality scorers: Daejon and Gyeonggi. While these two regions also represent significant differences with each of the thirteen remaining regions, two sample t-tests between them and the other regions could at least lead to a modified conclusion about the single-hub hypothesis, specifically that Seoul is trailed by a gamut of regions. As described in the previous section, we have divided the data into two time periods: pre- and post-1994. In the post-1994 period, the differences in centrality scores between Gyeonggi and Daejeon and the rest of the regions were statistically significant.[5] Results for the pre-1994 period, however, are presented in Table 3, which shows a number of regions on par with Daejeon and Gyeonggi. The centrality scores of Busan, Gangwon, and Jeonbuk are not statistically different from those of Gyeonggi and Daejeon. Gwangju is also not statistically different from Gyeonggi. These three to four regions at one time represented the potential for multiple – at least more than two (i.e., Gyeonggi and Daejeon) – regions to follow immediately behind Seoul in terms of centralization. From 1994, that potential was left untapped for all except Gyeonggi and Daejeon.

Table 3 here

The results from the tests of the first two hypotheses lead us to conclude that Seoul, Gyeonggi, and Daejeon stand apart from the rest of the country. The analysis over time also periods provides a ready segue to an analysis of the test results for our third hypothesis. Before quantitatively testing for patterns of convergence, though, let us engage in a qualitative analysis of centrality score trends for just these three regions. Shown in Fig. 2 across research specializations, Seoul's single-hub status is not clear across all research areas. In the following specializations, Seoul's centrality clearly (i.e., for at least five consecutive years before 2009) has begun to decline: agricultural (2005), clinical medicine (2004), physics (2004). Related to this point, the shift away from Seoul has primarily been toward Gyeonggi since the late 1990s, particularly in the following sectors: biology (since 1999), clinical medicine (since 1996), immunology (since 1997), microbiology (since 1998), molecular biology (between 1999 and 2000), neuroscience (since 1997), physics (since 2000), plants and animal science (between 1999

[5] These results are not presented here but are available upon request to the first author.

and 2000), psychiatry (between 2000 and 2001), social sciences (between 2001 and 2002), and space sciences (between 2001 and 2002). However, in the geosciences (since 1997) Daejeon has clearly passed Geyonggi. As well, Daejeon is consistently ahead of Gyeonggi in chemistry, but it seems to be converging with Gyeonggi.

Fig. 2 here

Other noteworthy observations, based on our review of Fig. 2, include the following: Seoul lost its centrality dominance in agriculture in the 1990s; Seoul has dominated computer science since the 2000s, while the 1990s were a toss-up between all the three regions; and pharmacology and engineering are shared equally between Gyeonggi and Daejeon. There are also a number of specializations that showed remarkable dynamics in select regions, particularly computer science for Daejeon, environmental science for Seoul and Daejeon, geosciences for Seoul, and mathematics for Seoul. All of these observations are interesting but must be examined formally; i.e., quantitatively.

To quantitatively identify patterns of convergence among Seoul, Gyeonggi, and Daejeon, we perform the Levin-Lin-Chu (Levin, et al., 2002) test for unit roots. The null hypothesis is that all the panels contain a unit root; that is, the time series of relative centrality scores is not stationary and there is no convergence. Rejection of the null hypothesis indicates stationarity and convergence. Rejection of the unit root hypothesis also indicates that relative centrality scores follow a random walk. This means that deviation among the three regions' time series becomes permanent (Dreher and Krieger, 2005). In addition, the Levin-Lin-Chu test assumes a common autoregressive parameter for all panels to deal with autocorrelation.

The results of the Levin-Lin-Chu unit-root tests differ across time periods. We focus on the effects of the IMF crisis, as the post-crisis period has clear trends that lead up to the present. The adjusted *t*-statistics for each unit-root-test are presented in Table 4. For several specializations, the pattern of convergence has been occurring for decades, while in others, it has been isolated to the post-IMF period. Chemistry, computer science, and engineering, in addition to the aggregated data for all specializations, for example, are converging across all three regions over the entire 1981-2009 period. On the other hand, geosciences, molecular biology, and plants and animal science show no convergence at any time specification. In the pre-IMF period, only immunology and neuroscience showed convergence across all three regions, but these results (and all other results in the pre-IMF period category) are biased from the large number of zeroes in the pre-1990 period. In the post-IMF period, however, convergence was identified in nearly three-quarters of the reported specializations: agriculture, biology, clinical medicine, environmental sciences, immunology, mathematics, materials sciences, microbiology, neuroscience, pharmacology, physics, psychiatry, social sciences, and space sciences.

Table 4 here

IV. Conclusion

This paper has examined the development of networks in Korea's national innovation system in order to provide further evidence of unbalanced centrality. Further verifying the findings of Shapiro, et al. (2010), Seoul continues to be the main research hub. This was verified explicitly through our single-hub test (the second hypothesis). Historically, the opportunity for other regions – besides Gyeonggi and Daejeon – to replicate Seoul's centrality ended in 1994. We attribute this to the limited application of the Cooperative R&D Promotion Law to Gyeonggi and Daejeon.[6] This does not mean, however, that there are not future opportunities for centrality in regions other than Seoul, Gyeonggi, and Daejeon.

Certainly Gyeonggi and Daejeon have been catching-up to Seoul over time. The unique data utilized in this paper have allowed us to make a much more detailed case for this. Our results confirmed that there are regional differences and there have been changes over time (via the test of the first hypothesis). More importantly, and in a number of specializations, these changes provide evidence of a pattern of convergence among Seoul, Gyeonggi, and Daejeon. With sufficient policy focus, particularly Korea's BK21, it appears as though our modified version of Hirshman's (1958) theory of income convergence applies to the Korean case. Yet, much like presence of income inequality across geographies, we have yet to witness high levels of centrality across Korea's regions. Further policy actions could promote convergence across even more regions than just the three. The launching of MEST and MKE, for example, may provide the necessary impetus for additional regions to increase their centrality in select

[6] It certainly did much to salvage, based on W. Lee (2000), a failed National R&D Program in Daeduk Science Town, as Daejeon is now a major research hub in certain specializations.

specializations. What is clear, though, is that structural changes are needed if other regions are to increase their centrality. This was the case with the NRDP to grow Daeduk Science Town in Daejeon and it was also the case follow the implementation of IMF reforms. The saturation of Seoul as a network hub, which may have already occurred, is another example of a requisite structural change for increased centrality in additional regions.

Now that we understand which regions dominate which specialization, the next logical step in the analysis of Korea's three research centers, at least based on centrality scores for Seoul, Gyeonggi, and Daejeon, is to assess the degree to which each of them collaborates with specific regions. This would be followed by a test of the hypothesis that collaboration with one of these hubs is positively contributing to research output. Thus, even if one of the non-top-three regions is not collaborating extensively with other regions, the effects of networking with Seoul, Gyeonggi, and Daejeon can lead to increased research output. We can also similarly explore the effects of collaboration with foreign entities: Which countries tend to collaborate with which network hub in Korea? Are any particular specializations emphasized?

Other future research, though, must take into account the changes described above in terms of an input-output analysis. Without understanding the inputs – i.e., levels of government funding – into each region, we cannot assess the impact it has had on increasing centrality beyond Seoul, Gyeonggi, and Daejeon. The next stage of analysis must do a comparative analysis of regional research output relative to each of the policy's impacts in terms of public R&D funding for collaboration.

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Tables and Figures

Fig. 1 Longitudinal centrality degrees for ten highest ranking geographic areas, publications aggregated across specializations

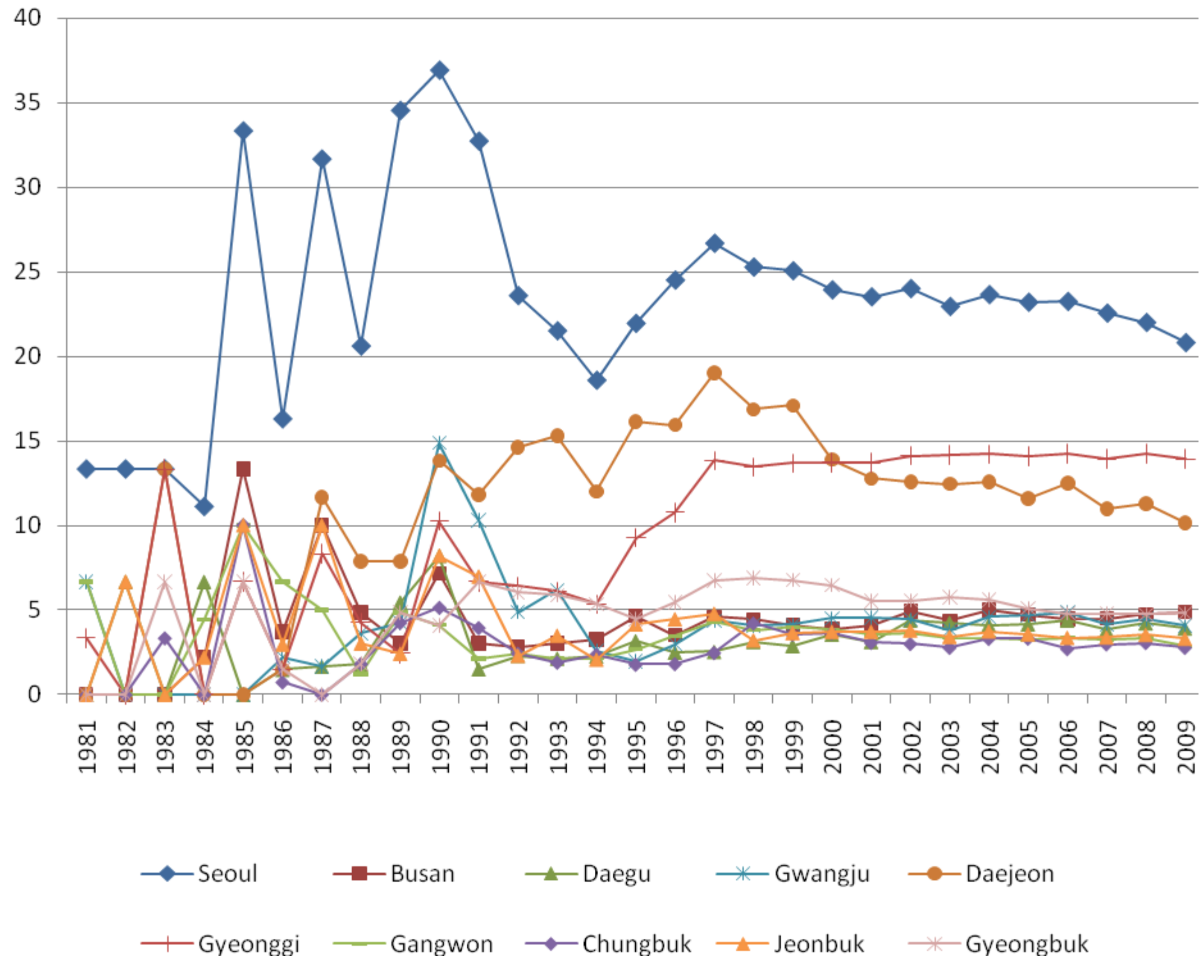


Table 1 Policy-related events and details from 1980 to the present

Year/period	Policy-Related Event	Details
1980-1986	Structural Adjustment Stage	Industrial deepening, tax credits for R&D, restructuring of GRIs
1982	National R&D Programs	Universities and firms could compete against GRIs for government funds
1986	Beginning of Internationalization Stage	Opening of research organizations in the public and private sectors
1993-1997	Government agencies dominated; IMF conditions applied	Cooperative R&D Promotion Law (1993) University support from MOST and MOE
1998-2002	Brain Korea 21 (BK21) project	Increased government subsidies to universities
2003-2007	BK21 continued	
From 2008	Launching of MEST and MKE	Mission: bolster innovation capacities across the country.

Source: Park and Leydesdorff (2010), W. Lee (2000), Kim and Dahlman (1992)

Table 2 OLS results for networks-specialization relationship test (1981-2009)

	(1) Year (percentage)	(2) Region (percentage)	(3) F-stat	(4) R2	(5) N
All SCI	2.08**	16.09**	7.73**	0.13	110
Agriculture	3.86**	18.4**	6.83*	0.09	69
Biology	3.94**	0.9*	11.92**	0.22	88
Chemistry	3.00**	2.17**	16.58**	0.25	102
Clinical	2.15*	0.77	3.64*	0.07	93
Computer	2.89**	8.75*	14.00**	0.26	84
Engineering	3.67*	1.42**	19.27**	0.29	99
Environment	4.60**	20.70**	13.71**	0.29	71
Geosciences	5.35**	9.78	15.52**	0.29	78
Immunology	3.14*	12.47	3.79*	0.11	67
Mathematics	5.77**	22.72**	20.62**	0.35	80
Materials	4.61**	14.61**	15.99**	0.28	87
Microbiology	3.43**	12.39*	6.82**	0.17	70
Molecular	4.03**	16.85**	11.14**	0.22	82
Neuroscience	0.22	0.39	0.01	0.00	64
Pharmacology	5.93**	11.55*	28.99**	0.43	81
Physics	3.35**	17.80**	9.29**	0.16	99
Plants & Animal	4.36**	2.37**	15.53**	0.28	84
Psychiatry	1.00	2.84	0.16	0.01	57
Social	3.76	5.14	1.71	0.05	63
Space	3.44**	4.88	5.16**	0.13	75

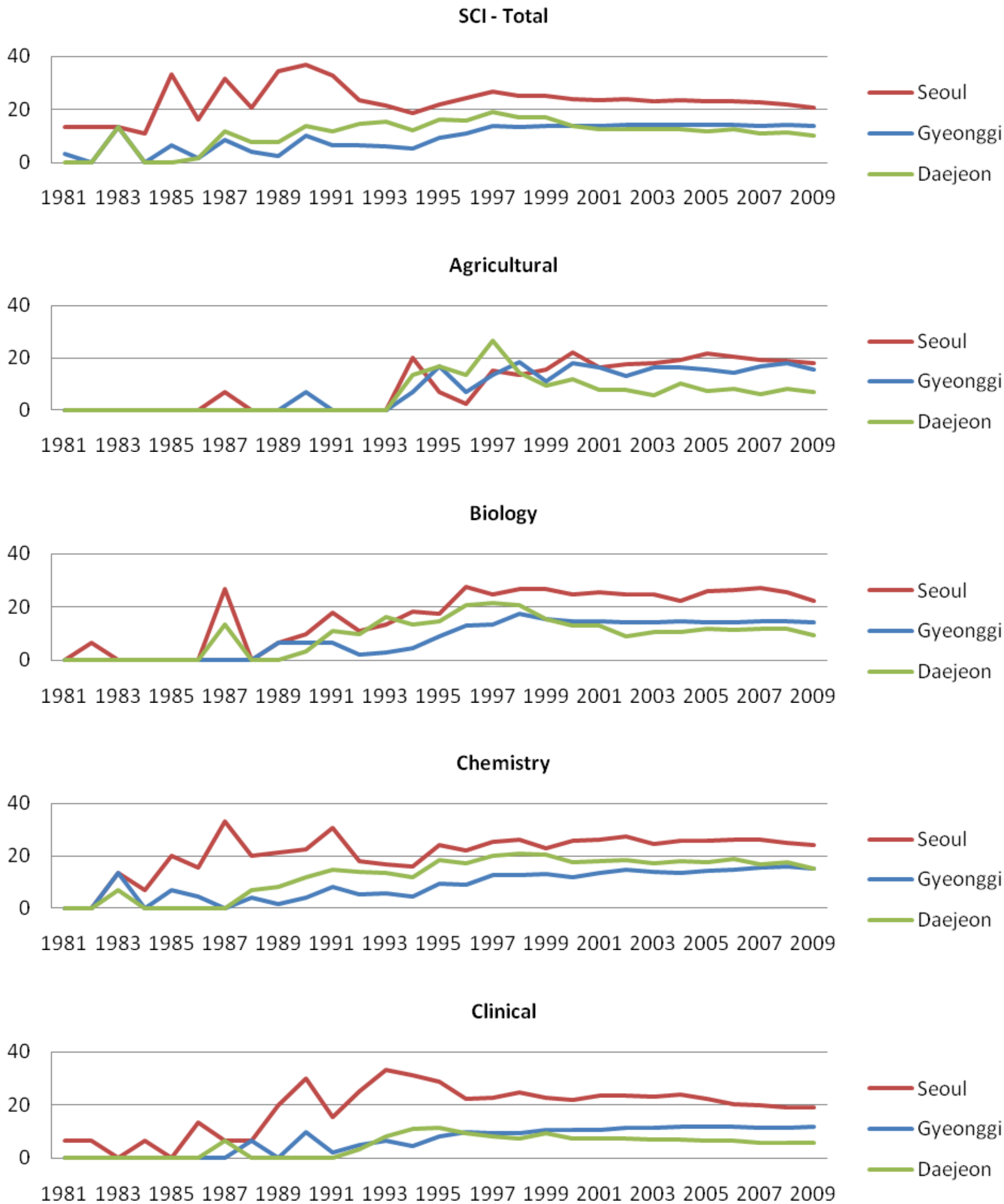
Note: ** and * represent statistical significance at the 1 and 5 percent levels, respectively.

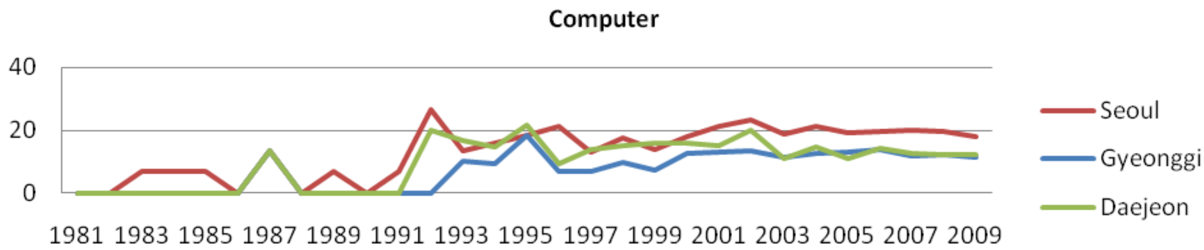
Table 3 Pre-1994, two sample t-test results for Gyeonggi-all regions and Daejeon-all regions comparisons

	(1) Daejeon	(2) Gyeonggi
Busan	$t(12) = 1.67$	$t(12) = 0.93$
Daegu	$t(12) = 2.36$*	$t(12) = 1.56$
Incheon	$t(12) = 2.99$**	$t(12) = 3.15$**
Gwangju	$t(12) = 2.09$*	$t(12) = 0.81$
Ulsan	$t(12) = 4.20$**	$t(12) = 4.41$**
Gangwon	$t(12) = 1.63$	$t(12) = 1.03$
Chungbuk	$t(12) = 2.67$*	$t(12) = 2.63$*
Chungnam	$t(12) = 2.74$*	$t(12) = 2.60$*
Jeonbuk	$t(12) = 1.54$	$t(12) = 0.64$
Jeonnam	$t(12) = 2.76$*	$t(12) = 2.81$*
Gyeongbuk	$t(12) = 2.82$*	$t(12) = 2.15$*
Gyeongnam	$t(12) = 3.76$**	$t(12) = 2.61$*
Jeju	$t(12) = 3.22$**	$t(12) = 3.66$**

Note: ** and * represent statistical significance at the 1 and 5 percent levels, respectively. Seoul is excluded from the results, as are the two groups from each other's comparisons. It has been established that the means of Seoul are significantly different from all groups, including Gyeonggi and Daejeon; Gyeonggi and Daejeon are not different from each other.

Figure 2 Centrality scores over time: Seoul, Gyeonggi, and Daejeon




Computer
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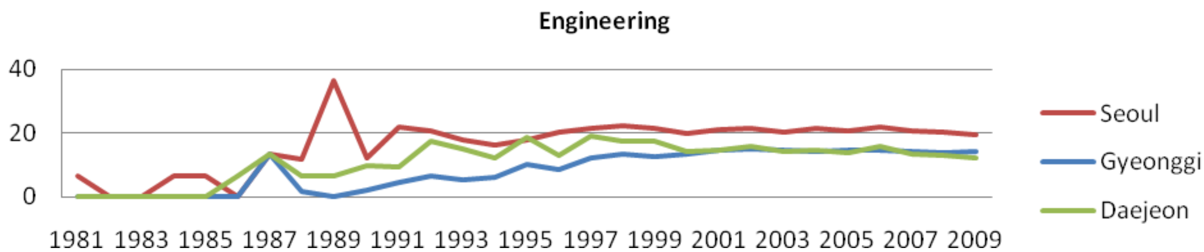
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
Daejeon


Engineering
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1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
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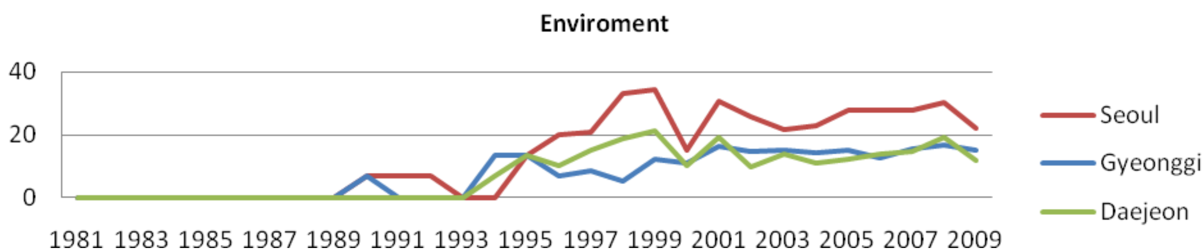
Enviroment
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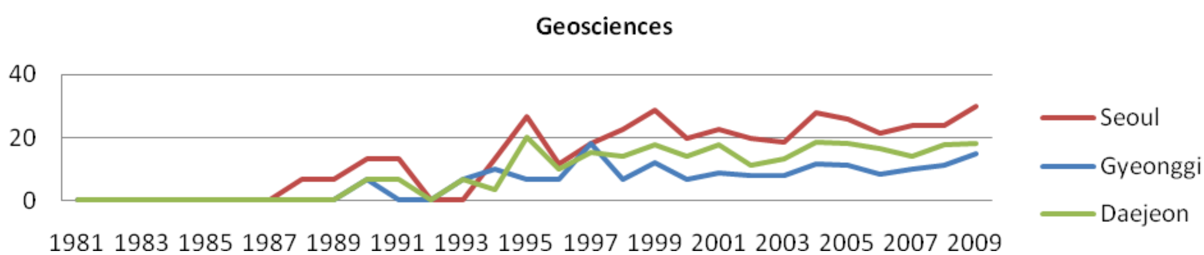
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
Daejeon


Geosciences
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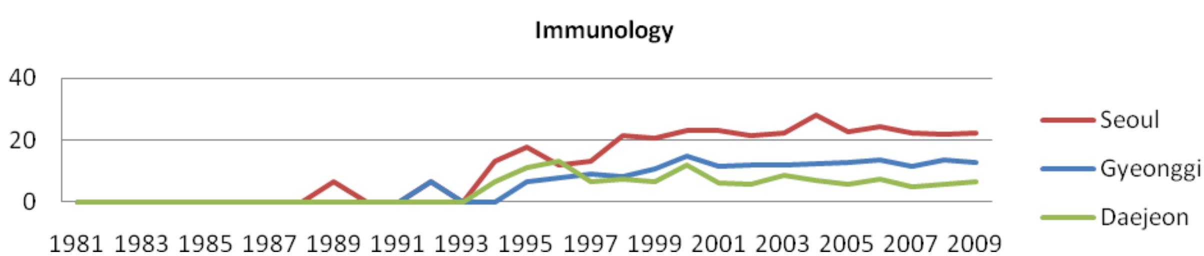
20
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
Daejeon


Immunology
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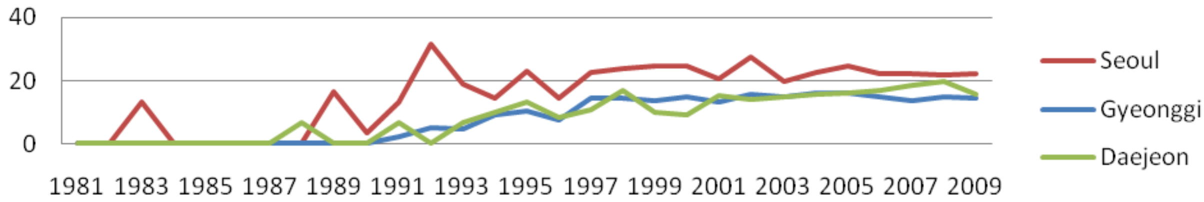
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
Daejeon

Materials



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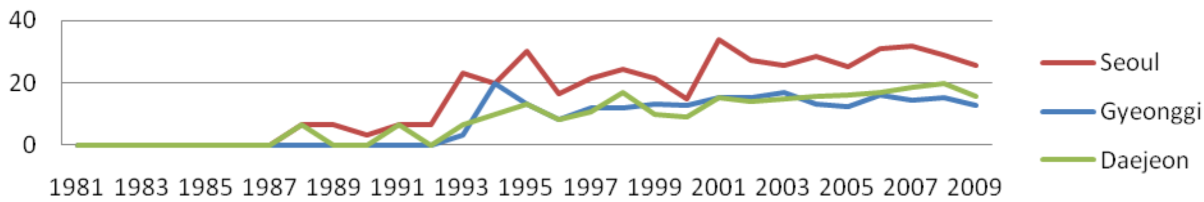

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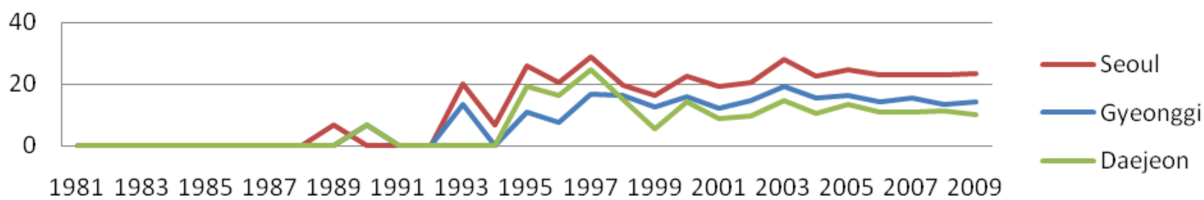

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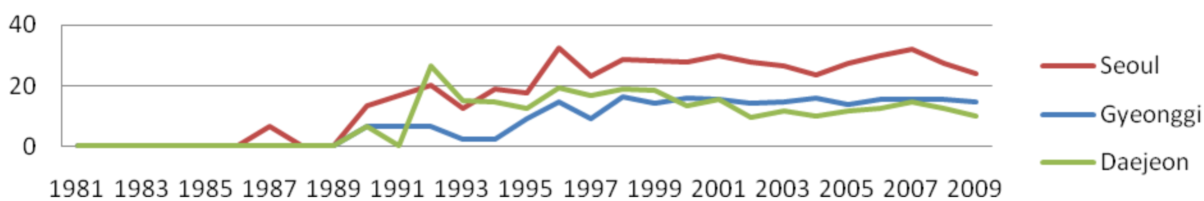

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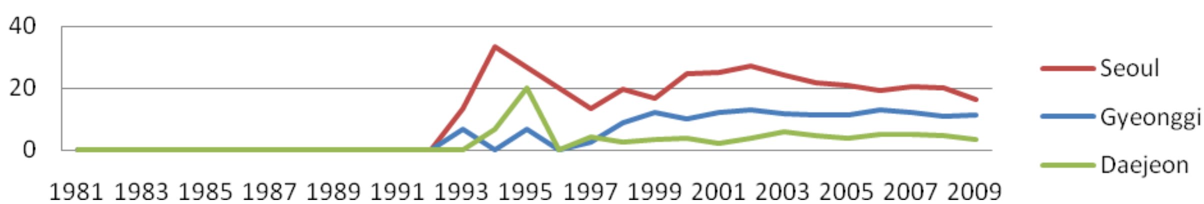

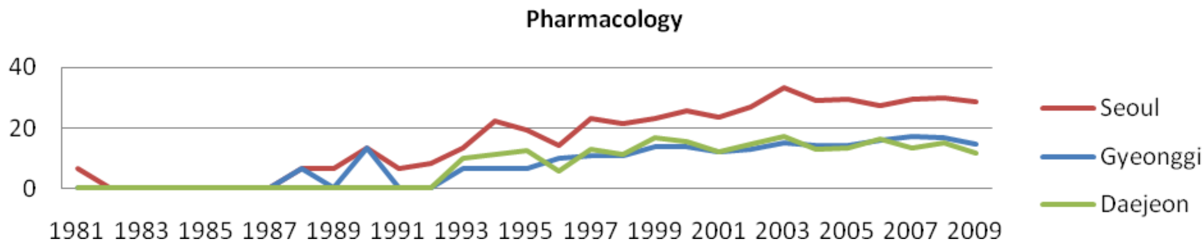
Pharmacology
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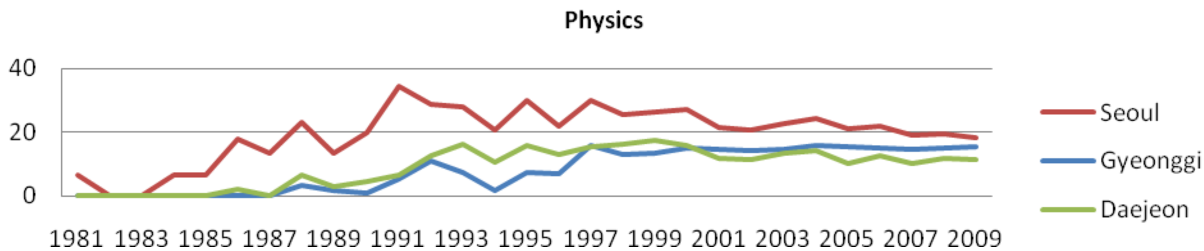
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
Daejeon


Physics
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1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
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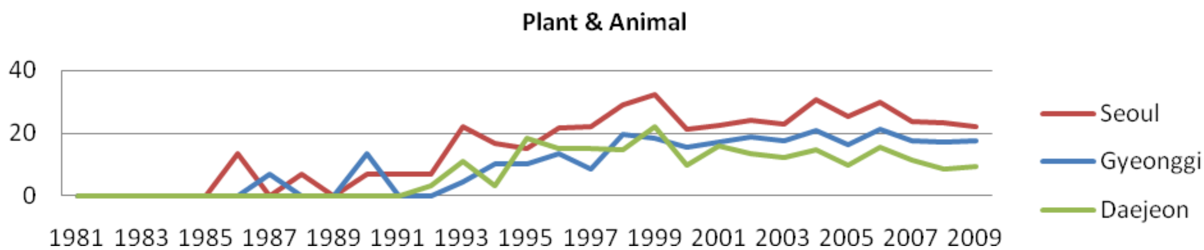
Plant & Animal
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1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
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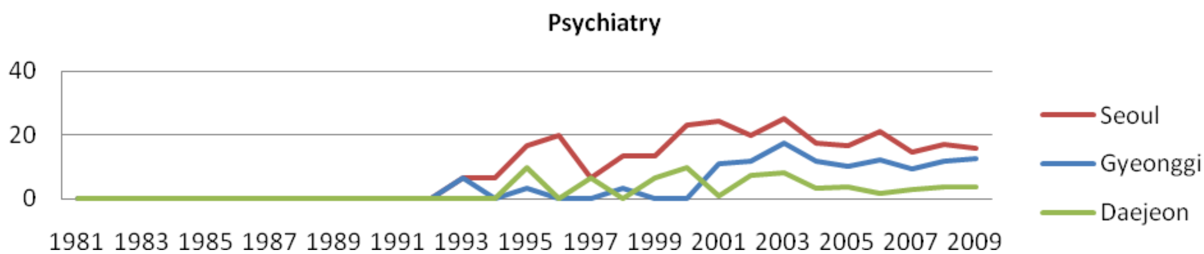
Psychiatry
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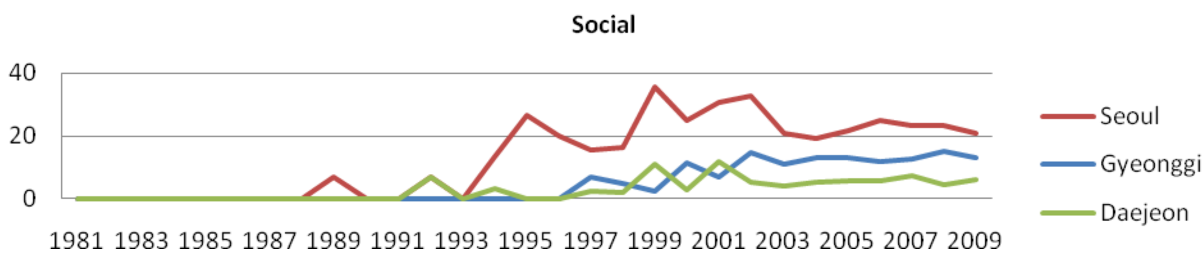
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
Daejeon


Social
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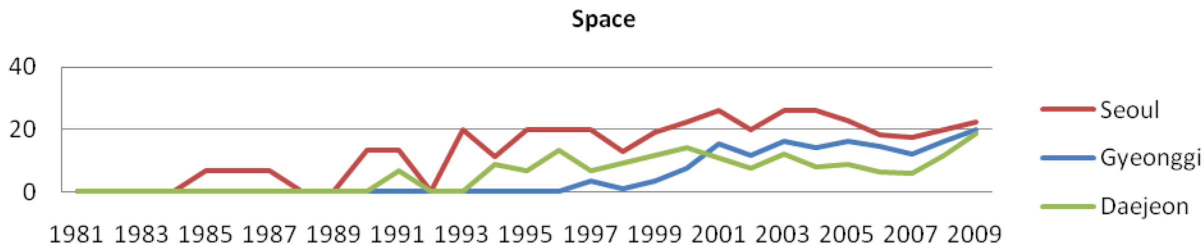
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
Daejeon


Space
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20
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1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Seoul
Gyeonggi
Daejeon

Table 4 Levin-Lin-Chu unit-root test results by specialization and time period

	(1) All years (1981-2009) N=3 T=29	(2) Pre-IMF (1981-1997) N=3 T=17	(3) Post-IMF (1998-2009) N=3 T=12
All SCI	*t*=-1.86*	*t*=-1.26	*t*=-1.61*
Agriculture	*t*=-0.071	*t*=2.48	*t*=-4.15**
Biology	*t*=-1.04	*t*=0.71	*t*=-6.64**
Chemistry	*t*=-2.41**	*t*=-1.16	*t*=-1.38
Clinical	*t*=-1.05	*t*=-0.28	*t*=-2.87*
Computer	*t*=-1.72*	*t*=-1.48	*t*=-0.77
Engineering	*t*=-1.77*	*t*=-0.97	*t*=-1.27
Environment	*t*=-0.49	*t*=1.50	*t*=-4.38**
Geosciences	*t*=-0.69	*t*=0.89	*t*=0.29
Immunology	*t*=-0.48	*t*=-1.69*	*t*=-3.51**
Mathematics	*t*=-0.69	*t*=-0.11	*t*=-1.93*
Materials	*t*=-0.76	*t*=1.62	*t*=-2.19*
Microbiology	*t*=-0.69	*t*=4.28	*t*=-7.28**
Molecular	*t*=-0.87	*t*=-0.03	*t*=-0.46
Neuroscience	*t*=-1.03	*t*=-1.76*	*t*=-1.67*
Pharmacology	*t*=-0.52	*t*=0.96	*t*=-3.76**
Physics	*t*=-1.25	*t*=0.06	*t*=-2.56**
Plants & Animal	*t*=-0.79	*t*=1.03	*t*=-0.69
Psychiatry	*t*=-0.45	*t*=-0.64	*t*=-1.90*
Social	*t*=0.42	*t*=0.72	*t*=-2.78**
Space	*t*=1.01	*t*=1.91	*t*=-2.46**

Note: ** and * represent statistical significance at the 1 and 5 percent levels, respectively. Adjusted *t*-statistics presented.