The Global Knowledge Linkage Structures of the Agricultural Sector Pertinent to Information Technology: A Triple Helix Perspective

Md. Dulal Hossain · Junghoon Moon · Young Chan Choe

Abstract The development of informatization impacts all sectors, including agriculture. Agricultural informatization builds the knowledge linkage structures of agricultural innovation systems globally. This study investigated the global knowledge linkage structures in agricultural innovation pertinent to information technology (IT) for agricultural research and development (R&D) investments and activities. We explored the longitudinal trend of systemness within the networked research relationships in the triple helix (TH) of the university, industry and government (UIG). We collected data from publications in the Science Citation Index (SCI), the Social Sciences Citation Index (SSCI), and the Arts and Humanities Citation Index (A&HCI) to analyze the TH network dynamics. We also performed a scientometrics analysis to quantitatively identify the knowledge and insights of global agricultural innovation structures. These results could be informative for individual countries. Our findings reveal that the global knowledge linkage structures in the agricultural sector that are pertinent to IT fluctuate widely and fail to increase the capacity of agricultural innovation research due to a neglect of the network effects of the TH dynamics of UIG.

Keywords Triple helix · Agricultural innovation · IT · Global knowledge linkage · University · Industry · Government

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1 Introduction

Globally, agriculture remains one of the dominant economic sectors, and agricultural research related to IT plays a vital role in building most of the world's economies. Agricultural research has enormous economic and social benefits, and its cost-benefit ratios can exceed those of nearly any other form of investment (Chambers and Ghildyal 1985). Innovations constitute an important economic output, and one prerequisite for innovation is knowledge linkage (Chatziparadeisis 2003). Innovation systems exist within firms and across the interfaces between institutional agents such as universities, industries, and government agencies. The knowledge production, diffusion, transfer, acquisition, absorption/assimilation, and use of these networks add value that should be measured (Chatziparadeisis 2003) to map the network effects of university, industry and government (UIG) in an attempt to build the knowledge linkage structures of innovation systems.

Numerous co-authorship studies in the international literature have explored the TH models of individual countries or groups of countries (Leydesdorff and Sun 2009; Park et al. 2005; Shapiro 2007). However, little is known about the global

trends in knowledge linkage structures of innovation in relation to the TH dynamics of UIG. In particular, the measure of the agricultural innovations related to IT is unexamined by researchers using the TH model. These gaps in the literature are the prime motivators for the research we present here.

The TH model of UIG relations (Etzkowitz and Leydesdorff 2000) permits us to study both the bilateral and the trilateral interactions among these three institutional domains in an innovation system. Therefore, in this study, we follow the design of Leydesdorff and Sun's (2009) study by operationalizing relationships in terms of the co-authorships in the literature contained in the SCI, SSCI and A&HCI (Leydesdorff and Sun 2009). In this paper, we address the following research questions: What are the quantitative features and characteristics of the global agricultural innovations that are pertinent to IT? How often do researchers working in different global institutions collaborate? What pattern do these co-authors relationships reveal? Based on the results, specific characteristics

of the global agricultural research system that are pertinent to IT will be further discussed.

2 Theoretical framework and literature review

The foundation of our theoretical framework is built on two elements: the scientometrics approach and the TH model. The scientometrics analysis provides knowledge and insights about the quantitative features of global agricultural innovation structures related to IT. Through the use of a TH model, which studies the relationship between academia, business, and government, the knowledge linkage structure of any R&D system can be examined (Etzkowitz 2008). Extensive literature shows that the TH model including these three independent UIG actors has the capability to capture both the dynamics within the three helices and new developments at the network level by demonstrating mutual information exchanges between the helices (Etzkowitz and Brisolla 1999; Leydesdorff 2003; Leydesdorff et al. 2006; Leydesdorff and Fritsch 2006; Park et al. 2005; Shapiro 2007).

Fig. 1 Institutional and functional differentiation in the knowledge-based age (Adapted from Leydesdorff and Scharnhorst 2003)

	University	Government	Industry
Science, Technology & Arts & Humanities	Science Citation Index (SCI-Extended)/Social Science Citation Index (SSCI)/Arts and Humanities Citation Index (A&HCI)		
Innovation in all fields	Quantitative features and characteristics provided by the Web of Science		

The literature also notes that this methodology can be used to analyze innovation systems other than nationally defined ones, such as sectorial, technological, and regional innovation systems (Carlsson 2006). In this study, we map the global knowledge linkage structures of the agricultural innovation systems that are related to IT (Fig. 1).

Agricultural innovation systems have changed with the rapidly changing global food and agriculture system. IT has played a crucial role in these changes

by contributing agricultural innovations through the improvement of economic growth. Agricultural IT innovations are important mechanisms by which agriculture adapts to future climate change (Parry 1990). A more systems-oriented understanding of how innovation occurs in an agricultural economy is critical to promote dynamism, responsiveness, and competitiveness in agriculture and to enhance productivity (Spielman and Kelemework 2009). Nevertheless, policymakers, investors, donors, and practitioners are unable to promote policies and

investments that foster innovation in agriculture without adequate measurements of the properties and performance of agricultural innovation systems. In these innovation systems, universities are the primary producers of knowledge, industries are the proxy for the economic factors, and the relevant level of government is responsible for interfacing with and organizing both university and industry functions at the systems level (Leydesdorff 2006).

The knowledge linkage structures within the agricultural sector differ across countries, and agricultural IT innovations have particularly changed with the advent of the Internet. For example, in the US, the proportion of farmers who had access to the Internet increased from 13% in 1997 to 29% in 1999. In the case of Australia, 58% of farms had computer access and 34% had Internet access by June 2000 (Rolfea et al. 2003). In Korea, the rate of Internet use in rural areas has exponentially increased since 1998. For example, only 0.6% of those who worked in the agriculture industry used the Internet; this percentage increased to 29.4% as of 2006 and continues to increase. Rural broadband accessibility in Korea was

at 81% in 2002 and increased to 100% in 2007 (Ministry of Food, Agriculture, Forestry and Fisheries, Korea).

3 Method and materials

3.1 Measuring TH dynamics

We used the entropy statistics introduced by Boltzmann and Shannon's information theory (Shannon 1948) for the measurement of TH dynamics. Entropy is used to measure the uncertainty or disorder of a given set of elements (Grupp 1990; Saviotti 1988). When variation is considered as a relative frequency or a probability distribution ($\sum_i P_i$), the Shannon-type information or the uncertainty contained in the distribution (H) is defined (Shannon 1948; Shannon and Weaver 1949) as follows:

$$H_i = -\sum_i P_i \log_2 (P_i). \qquad (1)$$

Equivalently, for a two-dimensional distribution, H_{ij} is represented by the following:

$$H_{ij} = -\sum_i \sum_j P_{ij} \log_2 (P_{ij}). \qquad (2)$$

Fig. 2 A TH configuration with negative and positive overlap between the three subsystems (Adapted from Park and Leydesdorff, 2010)
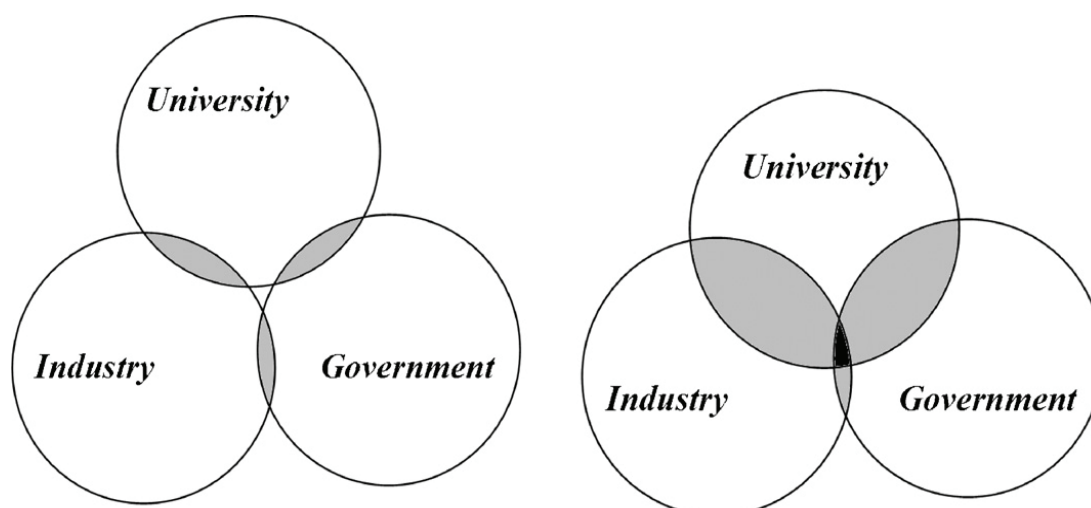
This uncertainty is the sum of the uncertainty in the two dimensions, reduced by their mutual

information; that is, the two variations overlap in their covariation and condition each other in the

remaining variations. Using information theory, mutual information can be written using the T of transmission between two distributions as follows:

$$H_{ij} = H_i + H_j - T_{ij} \qquad (3)$$

$$T_{ij} = H_i + H_j - H_{ij}. \qquad (4)$$

If the two distributions are completely independent (i.e., the covariation is zero), then T_{ij} is zero; otherwise, T_{ij} is positive (Theil 1972, p. 59f). According to the Abramson (1963, p. 129) derivation (Abramson 1963), the mutual information in three dimensions, using "u" for university, "i" for industry, and "g" for government, can be defined analogously as follows:

$$T_{uig} = H_u + H_i + H_g - H_{ui} - H_{ug} - H_{ig} + H_{uig}. \qquad (5)$$

Depending on the relative sizes of the contributing terms, the resulting indicators can be negative or positive (or zero), where a negative value indicates that uncertainty is reduced at the network level. McGill (McGill 1954) named this possible reduction of uncertainty "configurational information" (Jakulin and Bratko 2004; Yeung 2008). The reduction cannot be attributed to one of the contributors; hence, it cannot provide systemic network effects. The bilateral terms contribute to the reduction of uncertainty, while uncertainty in three dimensions adds to the uncertainty prevailing at the network level.

In Fig. 2, in the left-hand configuration, the system is not trilaterally centralized, whereas the common overlap between the three spheres in the right-hand picture supports a robust integration of both bilateral and trilateral relations. Central integration of UIG relations is considered desirable from a policy perspective to establish a competitive advantage at the national or regional level (Etzkowitz and Leydesdorff 2000; Mirowski and Sent 2007). This view of information in three dimensions allows us to measure the balance between the dynamics of integration and differentiation at the systems level by examining the relative frequencies of relationships between the partially overlapping sets. Overall, mutual information can be considered an information-theoretic analog of covariation, which reduces the uncertainty on both sides. Unlike covariance analysis between three or more variates,

information-theoretic measures are dimensionless and allow for comparisons between (quasi) experimental results that differ in their metrics (Garner and McGill 1956, p. 228).

3.2 Data collection

We collected data from the Web of Science (http://apps.isiknowledge.com), provided by the ISI of Thomson-Reuters. All papers were from the SCI, SSCI and A&HCI (1990-2011), and at least one IT-related study from the agriculture sector was collected from each database. This study focuses on global trends within publications in IT-related agricultural sectors. Therefore, the data consist of global bibliometric information on scientific papers with topics related to IT and agriculture.

To limit the search to papers relevant to IT and the agricultural sector, we entered the following search query: TS=(Agri* or Agro* not Agrou*) AND TS=(Information and Technology* or Information Communication Technology or ICT or Communication and technology*, Information and System* or Computer Science or Computer and System* or Telecommunication* or Telematics or Informatics or computing or software and system* or GIS or Information Management Systems or Management information System or MIS or Broadband Connectivity or Internet* or data mining or computer networks or mobile phone or smart phone or smart and technology* or Informatization or Ubiquitous or Supply chain Management or Farm to table or Food traceability system or e-business or e-commerce or e-government). TS is the query for topics. We picked "agri* or agro* not agrou*" as the search words because agri* comprises all words beginning with "agri-" (e.g., agriculture, agricultural, etc.), agro* comprises all words beginning with "agro-" (e.g., agrochemical, agronomics, etc.), and agrou* comprises words beginning with "agrou-" (e.g., aground), which are not related to agriculture. To identify all research pertinent to IT, the above-mentioned keywords for IT were used. We only collected data starting from 1990, although Web of Science provides bibliometric information on papers published from 1898. We limited the date range because there were few papers published before 1990 with topics related to IT and agriculture.

4 Data analysis

4.1 Descriptive statistics: Scientometrics approach

The scientometrics approach was first used for the data analysis to provide knowledge and insight on global agricultural innovation, including its quantitative features and characteristics. A total of 8,672 bibliometric data were collected from the period 1990-2011. A total of 8,059 papers in SCI, 1,371 papers in SSCI, and 75 papers in A&HCI that were pertinent to IT and the agricultural sectors were published in the ISI databases (Accessed on July 25, 2011).

Globally, yearly publications in the SCI, SSCI and A&HCI are increasing, with a sharp increase since 1996, as shown in Fig. 3.

Fig. 3 Number of globally published papers in the SCI, SSCI and A&HCI on the agricultural sector and pertinent to IT by publication year
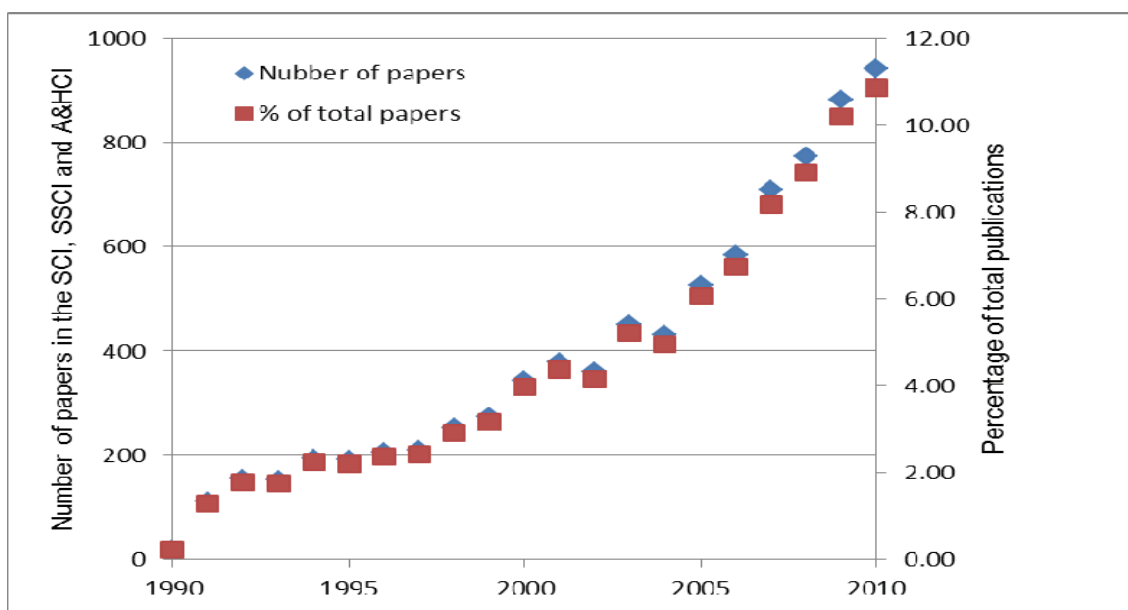

Fig. 4 illustrates the papers published globally by category; 93.22% were articles, and the remaining papers were published in other document formats, including notes, reviews, and editorial materials.

Fig. 4 Globally published papers in the SCI, SSCI and A&HCI relevant to the agricultural sector and IT by document type
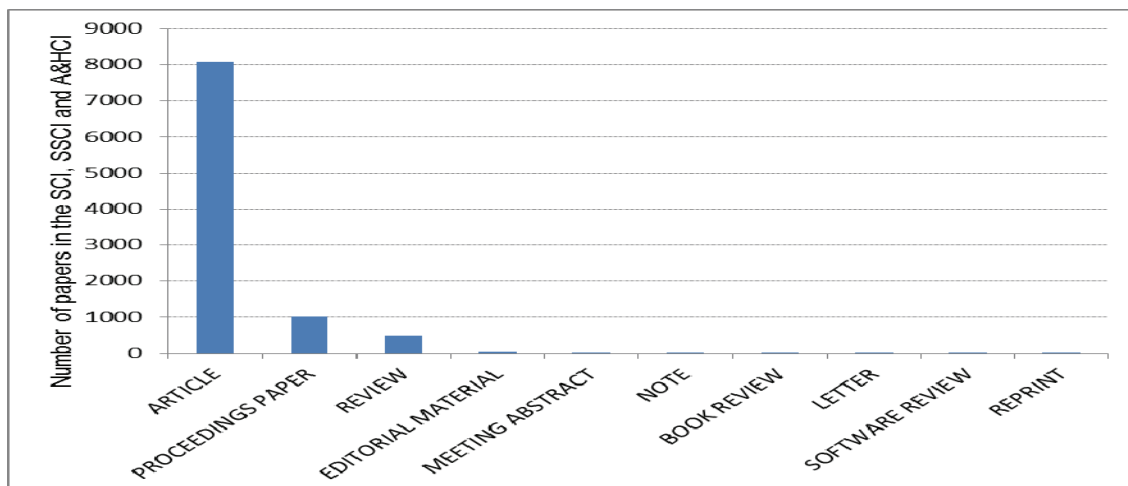
Fig. 5 shows the papers published globally by language: 95.95% were in English, and the remaining papers were published in other languages, such as German, Portuguese, and Spanish. Research publications in the subject area of agriculture were the largest share (36.19%), followed by environmental sciences ecology (28.16 %) and others, as shown in Fig. 6.

Fig. 5 Globally published papers in the SCI, SSCI and A&HCI on the agricultural sector and IT by language
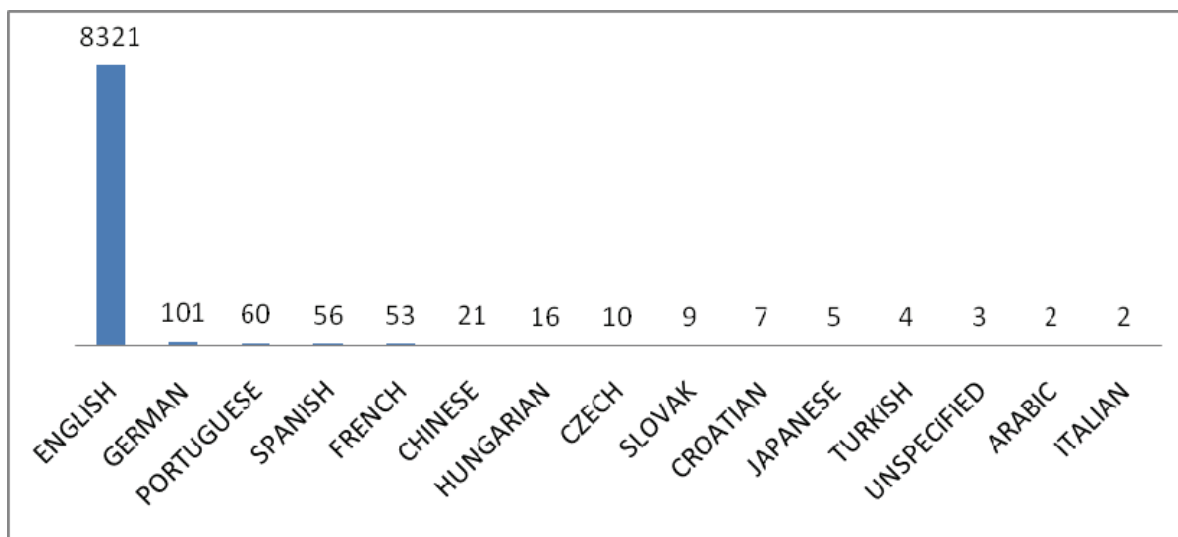
Fig. 6 Globally published papers in the SCI, SSCI and A&HCI on the agricultural sector and IT by subject area (first 50)
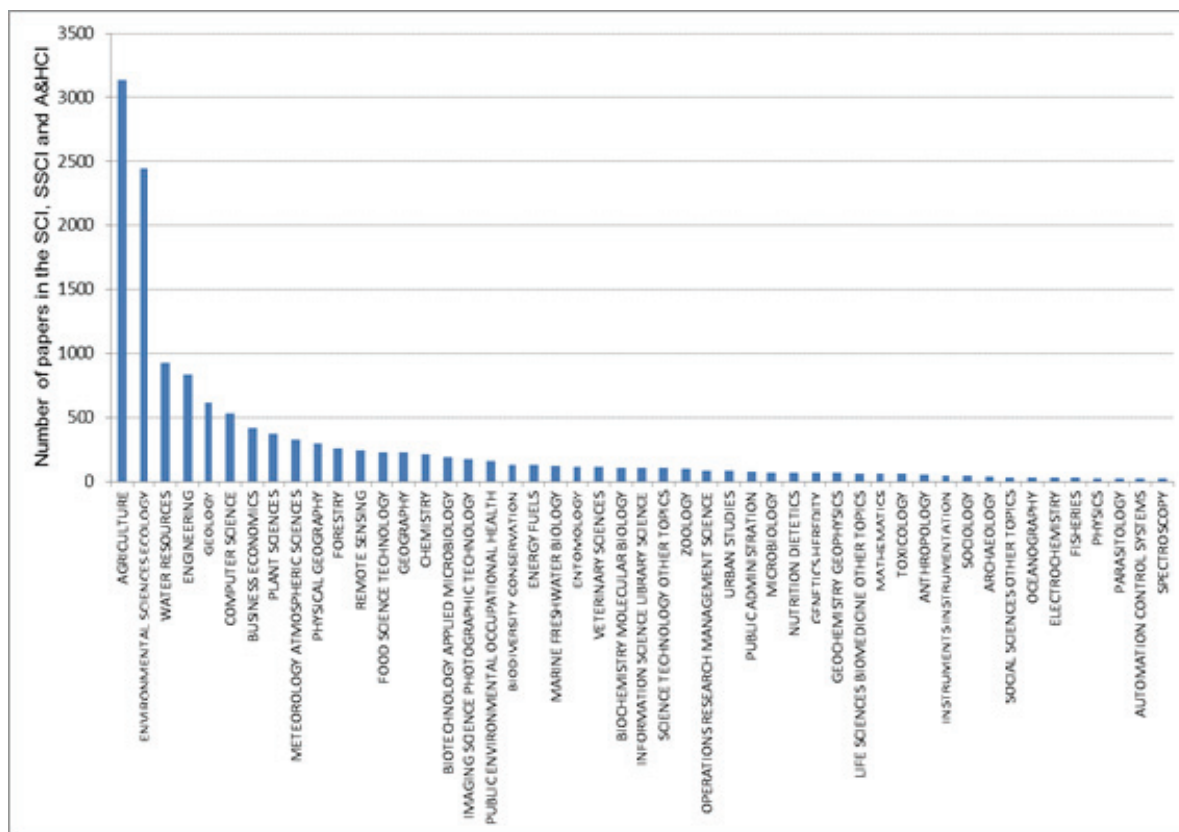
Approximately 40% of the research articles by global scientists came from just 50 institutions. The United States Department of Agriculture, Agriculture Research Service (USDA ARS) published the highest number of papers (3.55%) of all the institutions, as shown in Fig. 7. Of the records identified, 7,293 records (84.01%) did not contain data on the funding agency. The remaining articles were funded by the European Union (0.98%), the National Natural Science Foundation of China (0.67%), and the National Science Foundation of the US (0.60%), as shown in Fig. 8. Regarding the publication of globally published papers in the SCI, SSCI and A&HCI on IT in the agricultural sector by country, the U.S. published the highest numbers of papers (34.28%), whereas Korea published only 1.04%, as shown in Fig. 9.

Table 1 provides the digital economy rankings, which assess the quality of a country's IT infrastructure and the ability of its consumers, businesses and governments to use IT to their benefit. When we compare the published papers and digital economy rankings by country, we find dissimilar results regarding the ranking of the countries. This variation may be because the countries with the largest digital economies focused on industrialization rather than on digital agriculture.
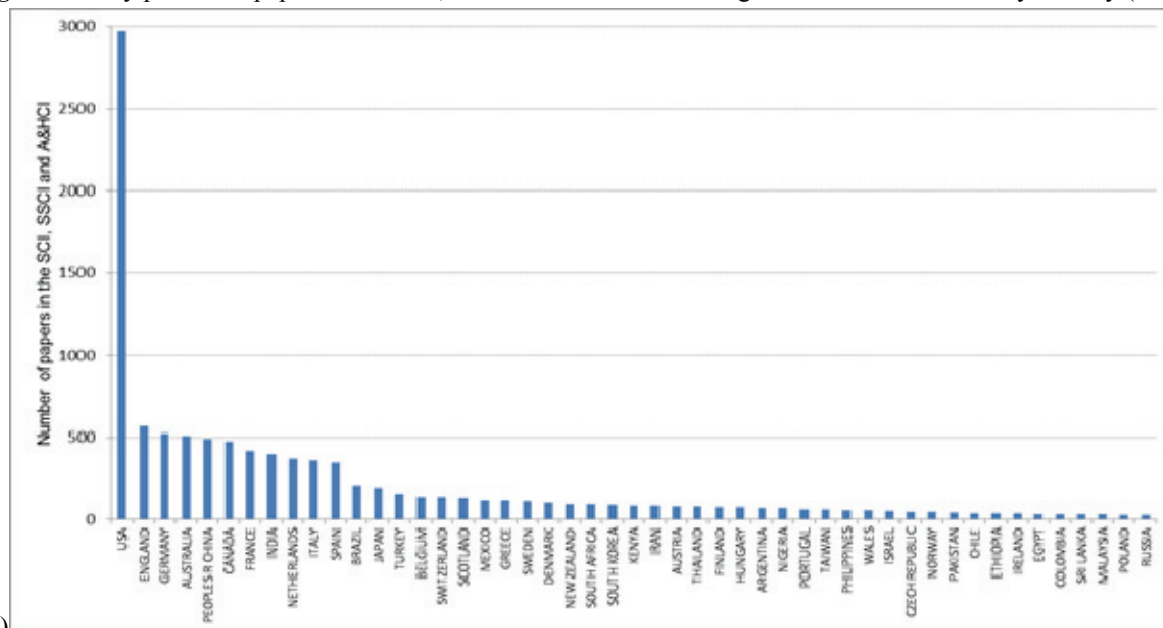
Fig. 7 Globally published papers in the SCI, SSCI and A&HCI on the agricultural sector and IT by institution (first 50)
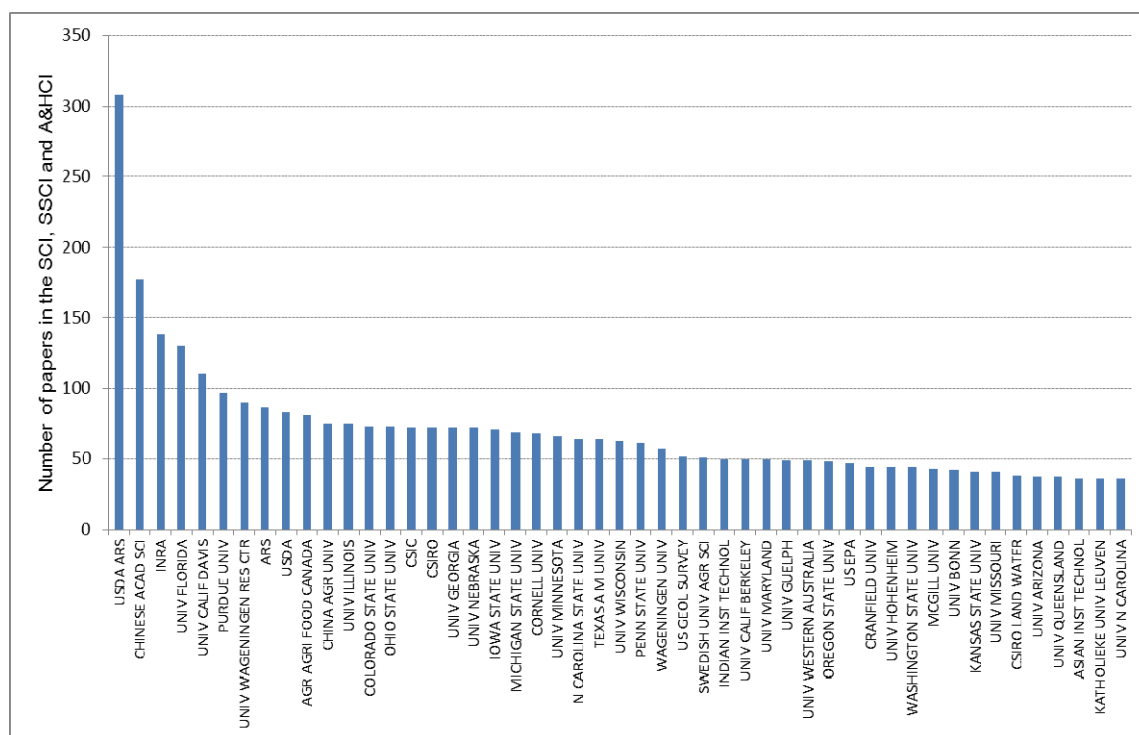
Fig. 8 Globally published papers in the SCI, SSCI and A&HCI on the agricultural sector and IT by funding agency (first 50)
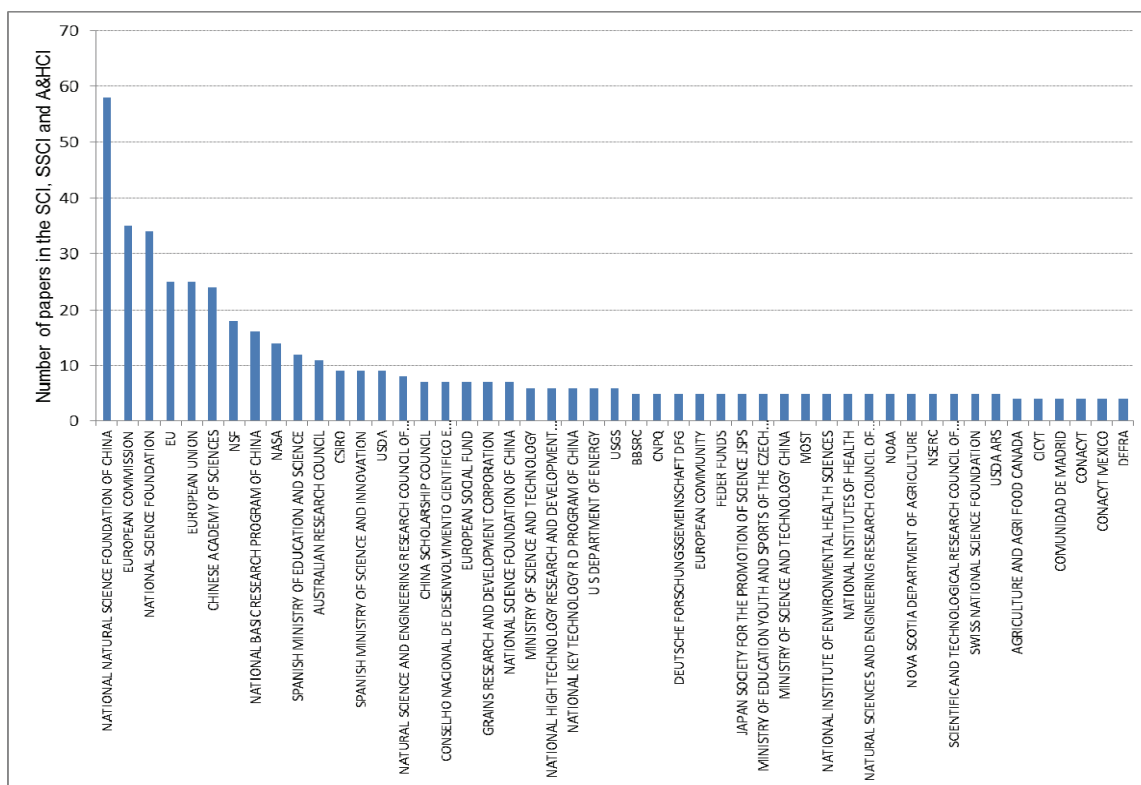
Fig. 9 Globally published papers in the SCI, SSCI and A&HCI on the agricultural sector and IT by country (first 50)

Table 1 Digital economy rankings and scores, 2010

| 2010 rank	Country	2010 score (of 10)
1	Sweden	8.49
2	Denmark	8.41
3	United States	8.41
4	Finland	8.36
5	Netherlands	8.36
6	Norway	8.24
7	Hong Kong	8.22
8	Singapore	8.22
9	Australia	8.21
10	New Zealand	8.07
11	Canada	8.05
12	Taiwan	7.99
13	South Korea	7.94
14	United Kingdom	7.89
15	Austria	7.88
16	Japan	7.85
17	Ireland	7.82
18	Germany	7.80
19	Switzerland	7.72
20	France	7.67
21	Belgium	7.52
22	Bermuda	7.47
23	Malta	7.32
24	Spain	7.31
25	Estonia	7.06

Source: Economist Intelligence Unit, 2010

4.2 Analysis of TH dynamics

The inputs for the TH analysis are the numbers of papers with only university authors, only industry authors, only government authors, only authors who are either from university or industry, and so on.

Collaboration patterns are measured by co-author relationships based on the SCI, SSCI and A&HCI data, as shown in Fig. 10. With some variation, collaboration patterns increased noticeably from 1996 to 2010.

Fig. 10 Globally published papers in the SCI, SSCI and A&HCI on the agricultural sector and IT by source title (Journal) (first 50)
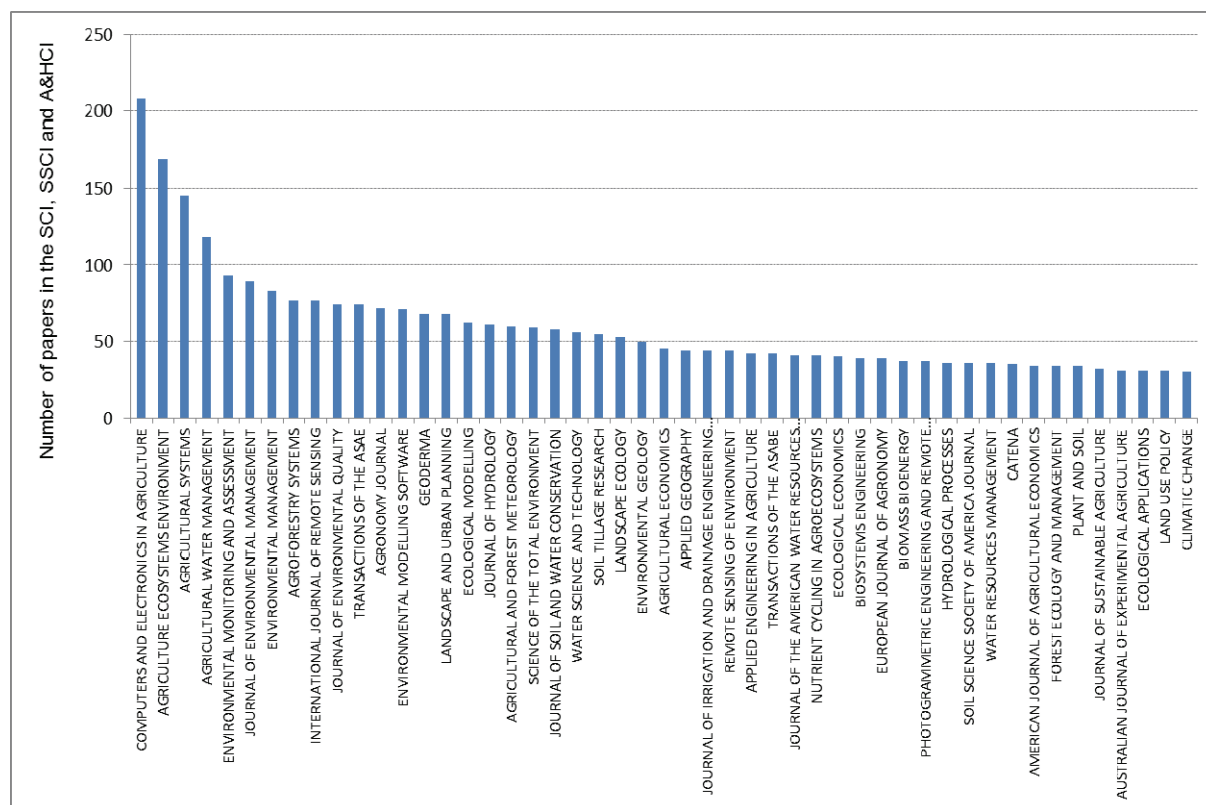
Globally, university addresses are involved in a high percentage (70%) of the published papers in most countries, including OECD countries. The percentage of articles that exclusively included an industrial address was consistently the lowest during the study period. This result was not affected by university-industry relations because this percentage also decreased during the study period. The linear regression in Fig. 11 is drawn to assist the reader

with the interpretation. In summary, these statistics indicated that there were decreasing triple-helix relationships in IT-related agricultural sector publications from 1991 to 2000 because of a decline in university-industry relationships, indicated by co-authored publications. However, the number of papers incorporating both industrial and government addresses remained low, both with and without university participation.

Fig. 11 Number of papers published globally in the SCI, SSCI and A&HCI on the agricultural sector and IT with bilateral and trilateral relations between TH sectors within the global economy
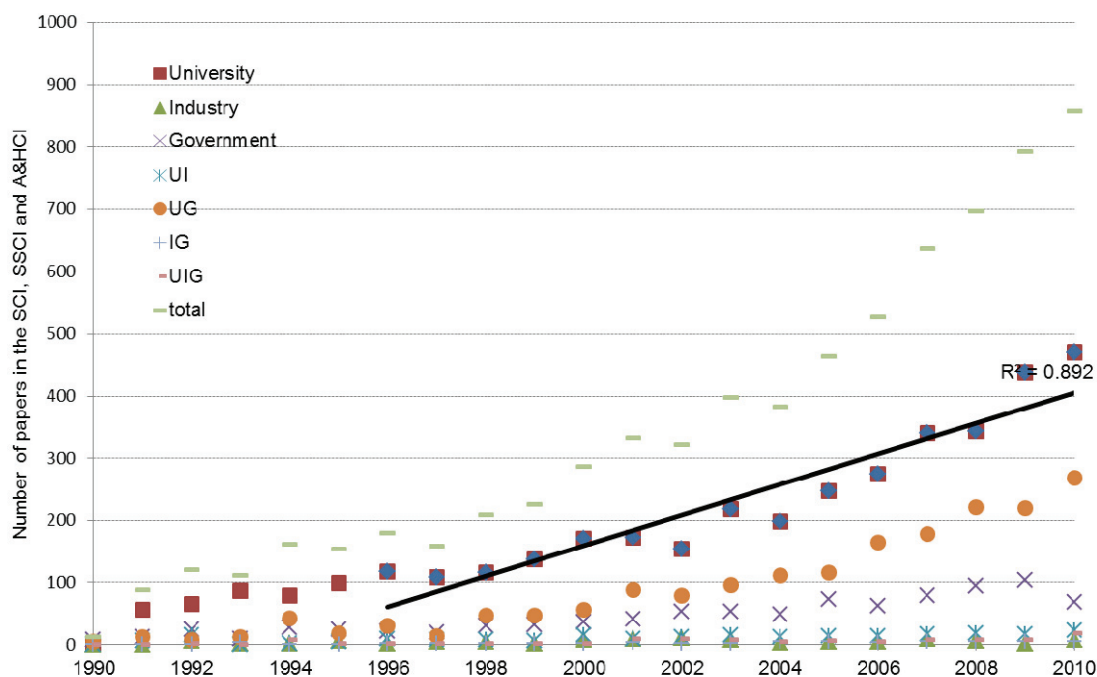

Fig. 12 illustrates IT-related agricultural research publications with mutual information on the bilateral relations between the TH sectors, as measured by co-author relationships. The UG research collaboration (Tug) showed the highest value, with 1.47 mbits of bilateral relations in 1991. While Tug values decreased in 1993 (0.23 mbits), UI collaborations began to blossom this year (0.74 mbits). The transmission value of UI co-author relationships (Tui) increased to 0.96 mbits in 1990. Mutual information between university and industries (Tui) has been stagnant, and there was more active scientific cooperation between the government and industry publications (Tig) than between university and industry publications (Tui) during 1995-2010.

Fig. 12 Mutual information measured in bilateral relations between TH sectors in the SCI, SSCI and A&HCI publications on the agricultural sector and IT, globally
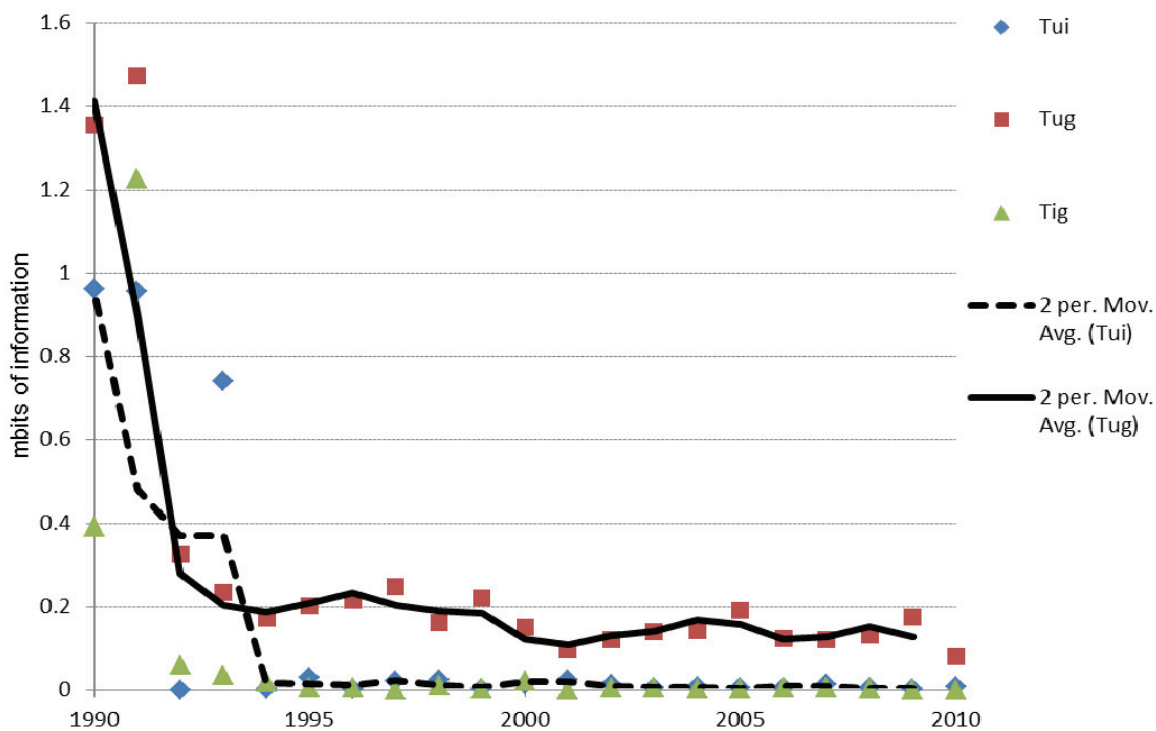
Fig. 13 Global publication rates of papers and synergy effects among TH sectors on the basis of co-author relationships in the SCI, SSCI and A&HCI on the agricultural sector and IT
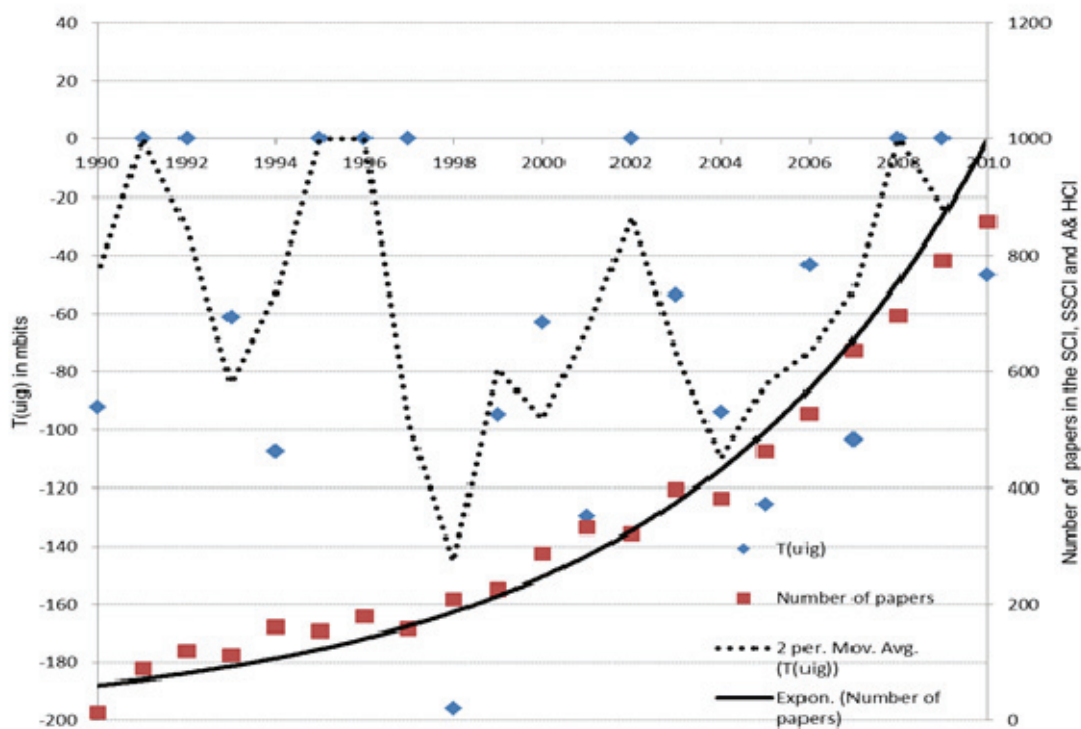
The TH indicator (Tuig) can also be negative due to a synergetic effect of TH relations, whereas the mutual information in the bilateral relations is positive by definition. Fig. 13 provides the longitudinal trend, expressed with two-year moving averages. This trend shows an interesting path between the three institutional domains. The information values of Tuig during 1990-2007 ranged from −92.23 mbits in 1990 to a minimum of −103.41 mbits in 2007. The mutual information between the three TH agencies (Tuig) remained relatively steady during the 1998-2007 period. The TH dynamics of UIG relationships varied considerably. This variation generally accords with changes in government research policies and institutional regulatory frameworks worldwide.

5 Discussion and conclusion

In this knowledge-based society, research fields and industrial structures are internationally organized, raising a number of control problems at the national level. Government intervention can no longer be expected to steer these developments. Global trends in the knowledge linkage structures of innovation within agricultural R&D systems are a complex construct of integrating and differentiating mechanisms. On the basis of UIG subsystems, differentiation is enforced within each of the helices of the TH model. In particular, academics wish to publish, industries wish to gain financially from collaborations, and policy makers wish to represent the public interest. Our results reveal that because of this differentiation, integration in TH relations became less central not only to policy making, but also to the dynamics of the knowledge linkage structures of innovation itself.

This study found that approximately 40% of research articles by global scientists came from just 50 institutions. The United States Department of Agriculture, Agriculture Research Service (USDA ARS) published the highest number of papers (3.55%) among all institutions. In regard to funding agencies, most articles were funded by the European Union (0.98%); the National Natural Science Foundation of China (0.67%) and the National Science Foundation of the U.S. (0.60%) were the second and third, respectively. By country, the U.S. published the largest numbers of papers (34.28%) on this topic, whereas Korea published only 1.04%. When we compare these results with the digital economy rankings, we find dissimilar country rankings for agricultural innovations compared to positions on IT. For example, Korea ranked first in the digital opportunity index (DOI) in 2007 and 13th in the digital economy rankings in 2010. However, Korea ranked 25th in terms of knowledge linkage structures in the agricultural sector related to IT. This variation may be because the highest-ranked digital economy countries focus on industrialization using IT rather than on digital agriculture. We also found that incentives at the institutional level were not equally distributed for all sectors. Consequently, the social sciences and humanities consistently lagged behind the natural and life sciences.

The implications of this study are produced by mapping the dynamics of the R&D knowledge linkage structures of agricultural innovations that are relevant to IT through science, technology, and innovation networks using the TH indicators. Our findings reveal that the global knowledge linkage structures of the agricultural sector and IT fluctuated frequently and failed to increase the research capacity for agricultural innovations because of a neglect of the network effects of the TH dynamics of UIG. From this study lesson, individual countries can compare their network effects in the TH dynamics of UIG with the global trends and can correct imbalances by reforming their agricultural R&D policies and emphasizing IT engagement. Greater collaboration between government institutions, universities and industry clusters can improve knowledge production and diffusion and increase commercial applicability by establishing agricultural innovations that engage with IT. We recommend that countries' national R&D research policies should be based less on strict quantitative performance measures and more on a balanced approach between bibliometric indices and the informed judgment of peers with expertise and academic maturity. We believe that including the network effects of the TH dynamics of UIG in policy will improve the knowledge linkage structures of agricultural research pertinent to IT by improving the agriculture economics of individual countries, ultimately leading to global development.

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