Title	Existing and Potential Indicators for Assessing University-Industry-Government Relations in Innovation Systems
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Citation	年次学術大会講演要旨集, 27: 304-308
Issue Date	2012-10-27
Type	Conference Paper
Text version	publisher
URL	http://hdl.handle.net/10119/11028
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Description	一般講演要旨

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Existing and Potential Indicators for Assessing University-Industry-Government Relations in Innovation Systems

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Abstract— **The selection and design of appropriate indicators are crucial for evaluating the outcome of university-industry-government (UIG) relationship in innovation systems at various levels. This paper reviews and compares current indicators and discusses the orientations for the design of potential new indicators that may complement existing ones. This paper then provides implications for policy-makers and evaluators.**

Index Terms— **university-industry-government relationship, innovation systems, indicator, research evaluation**

1. INTRODUCTION

The effectiveness of university-industry-government (UIG) relationship is a prerequisite for the achievement of sustainable socio-economic development in innovation systems at various levels in the era of knowledge-based economy, learning society [1, 2] and open innovation paradigm [3]. Among heterogeneous actors in a given innovation system, university, industrial firm and government agency can be regarded as the most important ones and thus UIG linkage network has naturally become the core sub innovation system.

It is relatively easier to measure the performance of a single actor; it is difficult to assess the effectiveness of combined efforts and interaction of two institutional settings (e.g. university-industry links) due to the complexity of their relationship; it is even elusive to gauge UIG relationship in the context of an innovation system because the inherent differences in missions and 'core competence' of the three spheres add to the complication.

Nevertheless, the evaluation of the effectiveness of UIG interaction in promoting innovation is necessary since it can inform and facilitate the formulation, implementation, adjustment or redesign and critical review of relevant policies, programs or projects or in the decision of the setting-up or reform of relevant intermediary organizations (e.g. liaison offices). Therefore, the crucial yet challenging task of selection and design of appropriate indicators for assessing UIG relationship becomes a major concern of evaluators.

However, most current indicators target the assessment of the effectiveness of knowledge transfer from universities and government labs to firms, i.e. public sector research (PSR)-industry relationship. Although the evaluation of PSR-industry linkage is a popular and meaningful approach, it obviously has its own limitations since it ignores the differences between universities and PRIs and avoids addressing the other roles other than research conducted by government labs on the part of government in the UIG sub innovation system.

Recently available proxies dedicated to measure UIG relationship, e.g. triple helix indicator, put great emphases on UIG co-authorship and thus is still limited in use in practice. Moreover, there are several other apparent restrictions with existing indicators. Our aim is to critically review these restrictions based on which we propose the possible orientations for the selection and design of potential new indicators to complement present ones.

The remainder of this paper is structured as follows: Section 2 put forth an overview of UIG relations in innovation promotion; Section 3 provides a review of existing indicators and methods for the evaluation of UIG relations; Section 4 point outs the limitations of existing indicators and highlights orientations for the selection and design of potential new ones; and Section 5 gives implications and draws a conclusion.

2. AN OVERVIEW OF UIG RELATIONS IN PROMOTING INNOVATION

2.1. Different core competences of UIG actors

Despite the trend that the boundary among universities, firms and government are getting ambiguous in the new innovation paradigm as they get more interconnected and their overlapping role expands [4], they still keep their core competences that reflects their identities. A lion's share of universities' resources is still utilized in improving the quality of education and basic research; government labs emphasizes fundamental and applied research; industrial firms are more dedicated to commercial activities and maximization of profits.

As regards research competence, the three actors have distinguishable 'comparative advantages' [5]. In general, government labs' core competence lies in its ability to carry out long-term, large-scope, high-risk and/or interdisciplinary or multidisciplinary state-of-the-art research with the backup of sufficient public research funding and tremendously expensive and often unique facilities that cannot be found in industrial and university labs. Moreover, PRIs can better grasp and respond to the expectations of government upon the development of strategically important technological areas.

The core competence of industrial R&D labs is their closeness to the marketplace and manufacturing site. Companies know far better about consumers' existing and potential demand and manufacturing than any other actor in innovation systems. Such knowledge informs corporate strategies in research, design and development of products, processes and services that are expected to be commercialized. In other words, these commercial entities' knowledge in other arenas apart from R&D in the innovation processes such as marketing, production and sales can help them reap the returns of R&D investment at a relatively higher successful rate and thus they can accrue revenues and profits far more than their counterparts in the public sector.

As for academic institutions, their core competence in promoting innovation is basic research characterized by the assistance of a large number of creative students who are cheap labors working below market wage rate in return for education [5]. As the future academics, scientists and engineers, industrial employees or start-up company owners, and government officials, students (both full-time and career students) and graduates are a means of knowledge transfer through employment and important brokers bridging universities with firms and government agencies as well as other actors in innovation systems. Thus, students make a notable difference in the generation, transmission and utilization of knowledge resulted from university research and thus they have a considerable impact on the three missions[1] of modern universities.

2.2. Motivations to involve in UIG linkage

What motivations pull university, industry and government together in the cause of stimulating innovation? Or as far as research is concerned, why universities, firms and government labs would like to forge linkage with one another? No matter whether such network is self-organized or organized by a third party, there must be cross-sphere synergy which means that actors from at least two of the three spheres can do things in a possible, more efficient or effective way when they work together than when they do not, though the benefits for each participant may differ.

A large body of literature has been concerned with the explanation of the motivators for the formation of bilateral UIG relations, i.e. university-industry linkage and government lab-industry partnership, especially the former and in particular firms' motivations. In the theoretical framework for the evaluation of university-industry relationships built by Bonaccorsi, A. and A. Piccaluga [6], firms' motivations to enter into interorganisational relations with university are considered to be:

- *Getting access to scientific frontiers.* This includes motives such as gaining early access to scientific breakthroughs and state-of-the-art information; retaining multiple research directions under conditions of pre-paradigmatic technology; employing highly skilled human resources; and creating barriers for competitors to access valuable knowledge.
- *Increasing the predictive power of science.* This includes reasons such as inspiring the development of mathematical modeling of design activities and problems and receiving training and support for in-house research
- *Delegation of development activities.* This comprises motivations such as risk sharing; cost reduction; solving specific technical problems; and getting access to large scale testing.
- *Tapping into complementary resources.* This covers rationales such as gaining access to university facilities (labs, tools, libraries) and reaching the scale for efficient management of facilities.

In a broader sense at the national level, UIG actors are still three distinct spheres; however, they are interconnected and only when they interact effectively can they create a healthy national innovation system. In a narrower sense at the activity level of doing research, we argue that different core competencies (including the associated complementary resources) of the three institutional settings have a signalling effect that can motivate one of the UIG actors to contact another one or two actors in the sub innovation system. For instance, the major motivations for a university or industrial lab to collaborate with a PRI can be gaining access to its knowledge in long-term and/or large-scale research projects and utilization of the unique research facilities located on its counterpart's premise while the main reasons for a government to associate with a university should include tapping into highly skilled researchers and students with complementary knowledge base as well as recruiting highly skilled students. Our analysis of a company's motivations to engage in a linkage with a university from the perspective of core competence is consistent with that of Bonaccorsi, A. and A. Piccaluga [6].

2.3. Mechanisms of interaction

From innovation system perspective, innovative actors do not stand alone but inevitably interact with other agents such as providers, users and competitors. In this paper, we focus on the positive relationship among UIG actors without considering situations where their counterproductive efforts take place (e.g. competition in

[1] It is worth noting that university has assumed an increasingly significant third role of knowledge capitalization alongside the other two traditional missions, i.e. teaching and research.

patenting activities or undertaking repetitive research due to the absence of communication or coordination). A succinct taxonomy of different types of mechanisms of interaction is suggested in Table 1. As is often the case with UIG bilateral or trilateral interaction, a portfolio of several channels instead of a single type is adopted.

TABLE 1
MECHANISMS OF INTERACTION

Mechanisms of Interaction	Formal	Informal
Two-way	Conference, cooperative R&D project, personnel exchange, merger	Meeting, Personal information exchange (via social connections)
One-way	contract, recruitment/hiring, technical assistance (use of facility), consultancy, training, on-site observation, licensing or sale of IP, spin-off, acquisition	Personal inquiry (via social connections) Donation,

Source: authors' elaborations

Regarding formal mechanisms, an agreement is usually signed by partners from all sides. Such an agreement describes responsibility, management (reflecting style of flexibility or control), governance, risk-benefit sharing, division of labor, task specification, conflict negotiation and organization structure in case of a project (centralization or decentralization). On the other hand, informal interface relies mainly on social network connections, e.g. know-how may be transferred through a casual private conversation between two friends who belong to different institutional settings.

Two-way mechanisms involve the co-creation or sharing or exchange of knowledge or other innovation resources. This two-way channel entails considerable negotiation and coordination throughout the whole interaction process where trust is the most important basis of cross-sphere relationships. On the contrary, one-way interface implies that one side takes all or most of the responsibility of a task, e.g. licensing or sale of intellectual property (IP) including patents, copyright, trademark and industrial design.

3. REVIEW OF EXISTING EVALUATION INDICATORS AND METHODS

Our literature review addresses the methodological issue of the evaluation of UIG relations (both bilateral and trilateral) by centering on existing indicators. The OECD's glossary on evaluation [7] defines an indicator as a " quantitative or qualitative factor or variable that provides a s imple and reliable means to measure achievement, to reflect the changes connected to an intervention, or to help assess the performance of a development actor." An indicator explicitly or implicitly describes the objectives of the evaluation in terms of target group(s) (who), timeframe (when), intervention area (where), quantity & quality (how much) etc. The insightful discussion in "A Methodological Perspective on the Evaluation of the Promotion of University–Industry–Government Relations" [8] shed some light on the issues pointing to the complexity of the assessment and the importance of measuring failure.

In a basic classification, indicators can be divided into direct and indirect ones. Unfortunately, given the complexity of UIG relationship, no direct indicators are readily available. All indicators such as traditional input and output data only partially and indirectly reflect changes exerted on or caused by the sub system; however, indirect indicators are indispensable in the meaningful work of evaluation.

Input-output data indicates what are used and produced respectively by a system or actor and input/output ratio can be a simple measure of its efficiency while throughput proxy reflects its processing ability (e.g. the average number of cases dealt with by a TTO every month and the rate of occurrence of interaction through a certain type of mechanism/channel). Input and output can be in the same form (e.g. monetary and IPR-related) and what is expected to change is the value added. Whilst output is the direct result of an intervention, outcome/impact is the mid-long term result and thus its measure is more demanding; both performance indicators should be taken into account when the effectiveness of the UIG relationship is gauged.

Table 2 shows a set of existing indicators of input, output and outcome/impact. For example, input indicators include human, financial, and commercial resources. One of the reasons these input, output and outcome indicators are widely used is that almost all of them are quantitative indicators which can be easily calculated from readily available databases.

TABLE 2
EXISTING INDICATORS OF INPUT, OUTPUT AND OUTCOME/IMPACT

Input	Output	Outcome/impact
Human, financial (e.g. R&D expenditure), physical (material, facilities, land), and commercial resources	Publications, Patents, Citations, Trademark, Process, Design, Copyright, Products	S&T advancement (export of knowledge-intensive products), Economic (licensing, spin-off, sales, rewards)

Source: authors' elaborations

Indicators relevant to bilateral UIG relations (most of which are also applicable in trilateral UIG relations assessment) also include those of technology or knowledge transfer from public sector to industry (e.g. licensing and spin-off). It is proposed that process indicators should be further developed to complement input-output indicators of technology transfer [9]. Faulkner, W. and J. Senker [10] suggested a set of comprehensive useful indicators for evaluating industry-PSR linkage in terms of intensity, channels, motivations and benefits of the cross-sphere relation by employing the concept of scientific and technological inputs (STI) or knowledge flows (Table 3).

TABLE 3
USEFUL INDICATORS OF INDUSTRY-PSR LINKAGE [10]

To what extent do companies interact with PSR?
'audits' of *the extent of linkage activity*, formal and informal assessment of the *relative significance* of STI from PSR (by comparing internal vs. external sources and PSR vs. other company sources)

How do companies interact with PSR?
examination of the *nature of linkage activity*, i.e. the different types or mechanisms of linkage
data on the relative use of different *channels* through which industry researchers obtain STI from PSR (i.e. literature, contacts and recruitment)

Why do companies interact with PSR?
examination of the *benefits* resulting from the range of linkage activity
data on the *type of STI* obtained from PSR (analysed in the context of the overall STI to innovation from all sources)
data on the *impact* of STI from PSR on company innovative activities (analysed in comparison with the impact of STI from all sources)

Concerning the evaluation of UIG trilateral relations, it is worth mentioning the triple helix indicator that is the mutual information (a concept in entropy statistics) among the three spheres [11]. The triple helix indicator is a relational proxy measuring the intensity of relations e.g. their interaction in publication activities as measured by coauthorship and co-occurrence/co-word relations in patent full texts or on the Internet [12]. Recently, a new approach of graphical modeling based on partial correlation for studying UIG relationships and relationships with other spheres using publication data has been proposed, which gives results that are consistent with triple helix indicator [13].

4. LIMITATIONS OF EXISTING INDICATORS AND ORIENTATIONS FOR THE DESIGN OF NEW ONES

There are also several limitations concerning current evaluation methods which provide room for the use and design of potential new proxies.

Firstly, existing input proxies (e.g. research grants and industrial funding) have apparent restrictions for being concerned with intent rather than success [14]. Furthermore, more attention should be paid to potential indicators of input, output and outcome/impact which can complement existing ones and help make a full picture of UIG linkage assessment. Table 4 suggests a small set of potential or emerging indicators of input, output and outcome which are seldom employed mainly due to the difficulty in data collection. Subjective survey instead of objective measure should be a b etter way of data capture when these indicators are used. For example, in the case of output indicator know-how, a survey on its value based on the subjective judgment of project managers (e.g. those of university-industry collaborative projects) should be a feasible approach. Notwithstanding, in the case of outcome indicators, measuring long-term outcomes/impacts can be most challenging. For example, in the case of economic impact resulted from UIG linkage such as the scale or potential of new market created, the amount of cost reduction, the number of new jobs generated and tax revenue increase, or in the case of social capital, innovation related networks and mobility of personnel across spheres, the data of these potential proxies cannot be easily derived due to the long time span.

TABLE 4
POTENTIAL/EMERGING INDICATORS OF INPUT, OUTPUT AND OUTCOME/IMPACT

Input	Output	Outcome/impact
Time, Social capital, Government power (programmatic incentives, tax credit etc)	Know-how, Secrecy, Services, Graduates (e.g. No. of career students), Cooperative research centers	Economic (new market, cost cut, new jobs, tax revenue), Social capital, innovation related networks and mobility of personnel across spheres, Education, Entrepreneurial culture, Political (e.g. new policies), Individual career promotion and reputation, Organizational image, Competitiveness, Capacity building

Source: authors' elaborations

Secondly, Input, output and outcome indicators suggest the linear innovation model which is widely disapproved [15]. In reality, UIG actors are more likely to interact reflexively within the framework of the Fifth Generation innovation model [16]. Therefore, evaluators should also consider the following innovation process arenas in which the interaction occurs, keeping in mind that Fifth Generation innovation model is characterized by non-linearity, feed-back loops, and cross-functionality (as well as interdisciplinarity and innovation networking) which means that any arena can lead to any other one without following the traditional order.

- Basic research
- Applied research
- Design research
- Development research
- Marketing research
- Manufacturing research
- …

Thirdly, there is a lack of assessment of UIG trilateral relations. Present indicators (e.g. triple helix indicator) dedicated to measure UIG trilateral relations focus on (though not exclusively) on coauthorship, which are limited in use. It is necessary to examine their trilateral relations in other innovation activities such as patenting and cooperative R&D project. Those indicators used to evaluate bilateral relations will also be helpful in measuring trilateral linkage.

Fourthly, we argue that the following indicators of context should be reflected.

- *Economic context:* For example, in the background of economic crisis unsuccessful UIG relations cannot just be attributed to ineffective interaction. Demand conditions and market potential for joint R&D and intensity of competition in an industry also affect actors' (esp. firms') motivations to establish cross-sphere linkage.
- *Political context:* Supporting legal framework and policies on IPR protection, cooperative R&D and technology transfer is vital.
- *Technological context:* existing knowledge base (tacit and codified) influences selection of partners and negotiation power.
- *Social context:* For example, the attitudes of public sector researchers towards commercialization.
- *Historical context:* i.e. history of UIG relationship

Fifthly, we put forth indicators of the system per se. For example, it is also meaningful to differentiate different scopes by asking "What is the level of innovation system in which the UIG spheres interplay? Supranational, national, regional, sectoral, or local level innovation system? How is the linkage organized and managed? Who leads?" The characteristics of UIG and supporting actors can be valuable proxies too, e.g. the size and reputation.

Sixthly, more indicators of motivations and interaction mechanisms should be created as the UIG relationships undergo continuous transformation which generates new motives and channels. Indicators of frictions, barriers and failures of the relationship are valuable too.

Finally, a systematic ad hoc indicator framework for evaluating UIG relationship has hitherto been not established. An attempt to make such a contribution should incorporate proxies of context, system, motivations, input, mechanism, output and outcome of UIG linkage into the framework.

5. CONCLUSIONS

This paper made a critical review of current indicators for evaluating UIG relations and discusses the orientations for the design of potential new indicators that may complement existing ones. We suggest a small set of potential or emerging indicators of input, output and outcome and point to the need of increasing the assessment of UIG trilateral relations as well as constructing indicators of context, the system per se, motivations and mechanisms and etc.

The implication is that policy-makers and evaluators should recognize the complex and dynamic nature of the task of assessing UIG relationship and adapt to alterations of situations by encouraging the use and design of potential new indicators and employing system thinking that considers all possible factors. For instance, evaluators should consider the innovation process arenas in which the interaction occurs, keeping in mind the Fifth Generation innovation model.

The next step of our research is to build a systematic ad hoc indicator framework for evaluating UIG relationships (encompassing both trilateral and bilateral types) by taking into account of proxies of context, system, motivations, input, mechanism, output and outcome of UIG linkage.

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