DEPARTMENT OF ECONOMICS WORKING PAPER SERIES

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Working Paper No: 2017-01

January 2017

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Abstract

This paper presents an intuitive model of university-industry (hereafter, UI) research linkages (or collaborations), focusing on the sharing principle under uncertainty. The paper draws from an earlier more complicated dynamic control theory model, but it differs in that it brings into the analysis of UI technical knowledge production and transfer the role of uncertainty (randomness) and the benefits of the principle of sharing. The main focus is to show how and why the principle of sharing under uncertainty benefits all entities involved in the technical knowledge production and transfer process, even if some entities experience research failure. Some problems associated with randomness are discussed. Operational aspects and policy value are also briefly discussed.

Keywords: University-Industry · Uncertainty · Cooperation · Sharing · Knowledge Transfer

JEL Classification: 030 · 031 · 032 · 033

Acknowledgments: The author would like to thank Methaya Monaiyapong for assistance with the references and the figures on earlier versions of the paper. Any errors or omissions are mine.

1 Introduction

This paper presents an intuitive model of university-industry (hereafter, UI) research linkages, focusing on the sharing principle under uncertainty. Such linkages are in the form of personal collaboration between the entities of UI and consists of research personnel visits (in person or electronically) from the "home" entity to the "site" entity for the purpose of collaborating on a research problem or project (National Science Foundation, 1983a, b). Out of such visits (or what has come to be called "sharing" activity) the production of technical knowledge (or information) at both ends is enhanced by the transfer back (imported) to the "home" entity and by the transfer from (exported) to the "site" entity. A very recent example of the UI model given in BusinessWeek is IBM's and others' collaboration on RND projects with UI entities throughout the world (See, Slywotzky, September 7, 2009; Hamm, September 7, 2009; and Walters, September 7, 2009). While each of the two entities could go it alone, it is the essential nature of the linkage (or sharing) approach to technical knowledge production that it results in complementarities or positive technical externalities among the entities. In other words, the whole is greater than the sum of the parts, greater by the positive interactions (resulting from sharing) among the entities in terms of technical knowledge production and transfer (See, Burk, 1999).

Various components of UI linkages have been in existence for some time in various countries. The formal recognition of UI linkages began with the National Science Foundation's study (1983a). Since then there have been literally hundreds of studies that discuss various aspects of UI linkages (such as linkage organizational structure, barriers to cooperative research, management issues, conflict resolution, cultural differences and their effect on cooperative research, financial issues, equity/payoff issues, policy/goals differences, and others). These aspects are discussed in various journals dealing with organization, management, finance, technology, economics, and policy. This literature is too vast to discuss here in any detail and frankly does not shed much light on the focus of this paper, sharing and the uncertainty of research results.

At a minimum, UI reviews and foundation material are useful from an historical perspective and can be found in, for example, Baldwin and Green, 1984; Reams, Jr., 1986; Allen, 1989; Geisler and Rubenstein, 1989; and Valentin 2002. For a thorough review since the 1997 literature, see Bozeman, Fay, and Slade, 2013. For a discussion of and references to barriers to cooperative research, see, Bruneel, D'Este, and Salter, 2010 and D'Este and Patel, 2007. Still, there does not appear to be any UI literature dealing explicitly with the link between research uncertainty and sharing.

With the exception of Gander's studies (Gander, 1986, and 1987), there have been few attempts to put the concept of UI linkages into a full, formal, dynamic, economic model. Some attempts have focused on organizational (institutional) and policy aspects (See, for example, Brodsky *et al*, 1980; Prager and Omenn, 1980; Peters and Fusfeld, 1982; Coursey and Bozeman, 1989; Tornquist and Hoenack, 1996; and Engineering Education and Centers Division Program, 2004).

There are several empirical studies providing quantitative measurement at the micro level (firm and university) of UI research linkages (For example, on quantitative measures of linkages, see, Gander, 1987; Fernandez, *et al.*, 1992; Wu, 2000; Schartinger, Schibany, and Gassler, 2001,, and Veugelers and Cassiman, 2005). A more recent empirical study along the lines of Gander, 1987, is Monaiyapong's on quantitative measures of research linkages in Thailand (Monaiyapong, 2004).

In any case, we find no UI literature directly focusing on the uncertainty of research results at the micro level and the role of the sharing principle. The present paper is an attempt to fill this literature gap and to develop a formal model in intuitive terms and to bring out the relationship between technical knowledge production and uncertainty and the sharing principle.

Conceptually, the various types of research linkages and the many organizational and contractual nuances make for a very complex system, if we try to model everything. The UI linkages can involve both the domestic economy and entities in other economies. We do not treat this involvement explicitly. To avoid getting lost in a maze of details, we develop a very simple model, taking several liberties with the definition of technical knowledge and linkages. One particular liberty to note is the aggregation of the many types and values of technical knowledge. Also, the contents of what constitutes a research visit to an entity are not explicitly spelled out in the model. Again, the reader should consult the literature cited for more details. Technical knowledge production and transfer have a substantial random component and the paper focuses on such randomness. We also do not attempt to differentiate between basic research, applied research, and developmental research.

In the next section we develop the intuitive UI model and introduce uncertainty into it under different random structures. Following that in the last section, we discuss its operational and policy value.

2 The Intuitive Model of UI Linkages

The essence of a complete UI research model including government (G) can be captured by the three-by-three rows and columns of Figure 1. The nine cells of the figure represent in a most general way the own and cross relationships or linkages.

Each cell has a diagonal to represent "visits" to an entity and "visits" from an entity. Such visits result in knowledge transfer that enhances the entity's own production of technical knowledge. In actual practice, there may be a common project where all three entities are working together (for example, designing a new fuel or a fuel efficient automobile). Or, the project may involve only two entities. Or, each entity may have its own projects and goals but sees fit to work cooperatively with the other entities in a mutually beneficial way such that each entity gains from the joint cooperation and knowledge sharing. For simplicity, however, we focus on the UI cells only and exclude any discussion of a complete UIG model.

The basic assumption of the paper is that cooperation in RND among firms and the sharing of technical information have been found to be beneficial to society and the firms involved in the cooperation (See, for an example of benefits, Wu and Wei, 1998; and for questionable benefits, See, Scott, 1988; d'Aspremont and Jacquemin, 1988; and Katz, 1986).

Exactly why a given firm or university, but particularly a profit seeking firm, would choose to participate in this kind of knowledge sharing is one of the key considerations of the paper. The entities could go it alone and each be concerned with its own problems and goals. But, as is often the case in the real world, technical problems are similar and mutual sharing and cooperation do exist. As will be explained later in greater detail, due to the uncertainty of the outcome of research activity, the uncertainty is greatly reduced under sharing and cooperation. Each entity learns from the others and each entity, in effect, provides benefits to the others. Whether there is a common project or individual projects, the sharing principle works the same. Uncertainty is reduced. How the benefits of a successful sharing operation are distributed among the entities involved is not a consideration of the paper. This consideration requires a game theory or bargaining approach and is not part of the paper's scope.

As indicated at the outset, uncertainty (or randomness) is an essential characteristic of the RND process of producing and transferring technical knowledge. Quite often it is fortuitous events that ultimately determine the outcome of research and its linkages.

The main proposition that we want to demonstrate is that with UI linkages (formal or informal) for transferring (and sharing) technical knowledge, it is not necessary for every entity to be a winner in its own endeavor. If one entity at an instant of time t is a loser, due to the transfer of knowledge from one entity to another entity (by discussions, report exchanges, or learning), the loser can still gain without any loss to the winner, since knowledge is not consumed like a commodity would be. The next instant of time t the loser may be a winner and the winner a loser, but still both gain. At some other instant of time *t*, both may be winners. The interaction cross effects due to UI linkages reinforce each other, so the growth of knowledge is very great. It is possible, of course, for all the entities at an instant of time *t* to come up losers. Hopefully, this is a rare event but one that is still possible nevertheless.

In keeping with the intent of the paper, we present an intuitive model to show the relationship between uncertainty and sharing. Assume that there are just two entities, a firm and a university. Assume further that the university is to work with the firm on a given technical problem. The firm benefits from the solution by selling the product. The university benefits by having perhaps an equity interest in the product and/or journal publications for the faculty involved. Figure 2 has a diagram of the basic technical knowledge stocks and flows and the personnel flows.

The firm and university have $K_1 + K_2$ and $\hat{}K_1 + \hat{}K_2$ respectively representing the stocks of technical knowledge. Separate identities are used for knowledge produced internally versus knowledge due to sharing and transfer. The $\Delta K_1 + \Delta K_2$ and $\hat{}\Delta K_1 + \hat{}\Delta K_2$ represent the flows of new knowledge into the stocks as a result of the personnel flows given by L_1, L_2 for the firm's research personnel and F_1 , F_2 for the university's research faculty (full or part-time). As indicated before, the K's and the ΔK's are shown separately to distinguish between knowledge produced directly and knowledge as a result of sharing and exchange of knowledge.

The L_1 is the firm's own research personnel input, F_2 represents visits of faculty from the university to the firm, K_1 is the firm's own knowledge stock, ΔK_1 is the direct flow, K_2 is the firm's stock of knowledge gained by past transfers and linkages, ΔK_2 is the flow of transferred knowledge due to the faculty (F_2) visits, and L_2 represents the firm's visits to the university producing knowledge flow $\hat{}\Delta K_2$ at the university and due to the rotation knowledge flow ΔK_2 at the firm. The U's in Figure 2 represent the random shocks to knowledge production and transfer, assumed independent of each other for now.

For the university we have F_1 representing faculty at home producing knowledge flow , $\hat{}\Delta K_1$, F_2 representing the faculty visiting the firm and rotating back producing knowledge flows, ΔK_2 and $\hat{}\Delta K_2$, as it moves back and forth between the entities. The

^U's are the random shocks affecting $\hat{}\Delta K_1$ and $\hat{}\Delta K_2$. The back and forth movement of personnel or interaction or sharing is between firm and university but could just as well be between two firms or two universities.

Ignore random shocks U_2 and $\hat{}U_2$ for the moment and focus only on U_1 and $\hat{U}_1$ shocks on direct production and take all the inputs and *K*'s as given and fixed initially. Assume these random shocks take on values 0, 1, 2 and both have the same uniform probability distribution (see Figure 3). The 0 is for no positive effect (or no new knowledge), the 1 for some positive effect (or some new knowledge), and the 2 for a large positive effect (significant new knowledge). No negative effects are assumed. The probability $P(U_1) = P(\hat{U}_1) = 1/3$. We are interested in the net effects of the random shocks, so we normalize the ΔK's for the effects of the inputs and the *K* stocks. The joint probability distribution is given by $P(U_1)P(\hat{U}_1) = 1/9$ for any one of the nine events shown in the sample space of Figure 3. The chance of both entities coming up losers at an instant of time *t* is 1/9. But, the chance of both coming up winners (values 1 or 2 or both) is 8/9, since both can win or one can win and the other lose but still in effect win due to the transfer of knowledge from the winner to the loser (for a discussion on de-contextualize knowledge due to transfer, see, Ahrweiler, Kueppers, and Kuhlmann, 1998).

Admittedly, this is an idealistic case. But, the point is that under UI linkages, the pooling of risks makes both players winners when it comes to technical knowledge transfer. If the firm wins and the university loses, then net ΔK_1 is positive for the firm, but the net $\hat{}K_2$ for the university is now increased as a result of F_2 faculty transferring back to the university the added (and shared) knowledge gained by the firm. Without the UI linkages, the firm would gain net additional knowledge from its positive random shocks and the university separately would gain from its positive shocks (points 2,3 and 4,7 in Figure 3). Due to the sharing, the UI linkages reinforce the knowledge production and transfer process. Without the linkages there is only a $(4/9)^{th}$ chance of both winning (U_1 and $\hat{}U_1$ = > 1) compared to the $(8/9)^{th}$ chance under UI sharing. In other words, under sharing what the firm learns helps the university and what the university learns helps the firm. Of course, realistically some duplication is possible, but such redundancy can be of value by reinforcing convictions. This is particularly true, for example, with cooperative research in the drug industry and in the aerospace industry.

Even for the simplest UI system, its behavior can be very complex. In Figure 4, we try to capture the net effects on internal knowledge production and knowledge transfer from the four jointly independent random shocks affecting all four knowledge flows. Given the same random values as before (0, 1, 2) for each U_i and $\hat{}U_i$ (i = 1,2), various behavior scenarios can be described. The diagonal vectors in the figure represent the between-entities (both ways). The vertical vectors represent the interactions within the entities. The four-dimensional sample space has 81 points or combinations. The joint probability that all four random U_i's (a given combination) are zero is very small, $P(U_1)P(U_2)P(\hat{}U_1)P(\hat{}U_2)$ = (1/3)*(1/3)*(1/3)*(1/3) = 1/81, but the chance that any four-way joint event has at least one or more positive elements is 80/81. Even if only one random element (out of the four) is positive (values 1 or 2) in any four-way joint event ((0,0,0,1) or (0,0,0,2) permutated four times), resulting in a small chance of 8/81, due to the transfer of knowledge under our assumed ideal conditions, both entities come out winners. For example, if only U_1 is positive (values 1 or 2) and all the other *U*'s are zero, all the *K*'s will still benefit due to the interactions within the entities and the transfers between the entities. Knowledge gained is not consumed by a transfer. So, even if only one entity gains, sharing will benefit all the other entities.

Admittedly, there are private property considerations implicit in the sharing process. There are also ego and psychological considerations. The literature cited earlier discusses some of these considerations. For example, university faculty want assurance that what they learn at the other entities (particularly, at the firm) can be published within a reasonable time period. Unfortunately, this assurance is not always forthcoming from the firm or even from the government (if the project involves national security). We do not discuss these institutional and contractual or bargaining problems here to keep within the scope and intent of the paper.

It is possible, of course, that the random shocks are not independent of each other. Say, for example, with U_2 and $\hat{}U_2$ only, they are perfectly correlated. Then, only events (0, 0), (1, 1), and (2, 2) will occur, each with a probability of 1/3. The chance of both entities losing (0, 0) is greater than under independency (1/3 > 1/9). The chance of both wining is 2/3, which is less than the 8/9th chance under UI, as explained above. The problem is that dependent random shocks can occur, although perhaps relatively infrequently. Nevertheless, it is possible that the institutional or organizational structure of any system designed to bring some formality to the UI linkages could turn out to be such that joint probability dependency results. In any event, the principle of sharing will still be effective.

How is it possible for all entities to be subject to correlated random shocks? If, for example, the researchers of each entity are influenced (controlled) by the same force (information, politics, whatever), they may all follow the same procedure or possible solution to a problem. A UI research team may be constrained due to organizational elements to follow a set research procedure or set of rules to the exclusion of other options, resulting in an overlap of the two probability spaces (for example, U_2 and $\hat{}U_2$). If the solution is correct, then fine. But, if it is not correct, then knowledge production and transfer will be severely affected. Having all entities subject to one administrative control may, therefore, result in probability dependency. Even worse, it may rule out the acceptance of randomness itself in knowledge production and transfer.

3 Summary and Conclusions

The formal and dynamic model of UI research linkages developed elsewhere was recast as a simple, intuitive uncertainty model. The important part of the intuitive model (Figure 2) is the four knowledge flows, representing the production flow of technical knowledge and its transfer (by sharing) from the entity in question to the other entity. Randomness was introduced into the structure of these flows to capture the essential behavior of the model of UI linkages and the random nature of knowledge production and transfer.

The basic proposition is that given the independence of random shocks in knowledge production and transfer, under UI linkages and at any instant of time *t*, all the entities involved in a given project or research problem ideally will most likely come out winners, even if some individually are losers as long as at least one is a winner. So the growth of technical knowledge is not hindered by a failure among some of the entities. The essential sharing (transferring) of knowledge principle makes all entities winners, even when only one entity is a winner at an instant of time *t*. Under jointly dependent randomness, this ideal result is still possible, although not as likely. Such joint dependency can result from a poorly designed organization, structured to give organizational formality to the UI research linkages.

Operationally, as noted in the literature cited earlier the K's and ΔK's can be measured typically as RND is measured in the literature by research expenditures, research personnel, or research hours. It is possible that the firm and the university could have their own metric ways of measuring knowledge. The present digital age allows for any number of possible ways about which we do not speculate at this time.

The policy value of our model as constructed here rests not so much with its operational potential, but with its insights into how UI linkages behave under randomness. The individual probability of failure can be high but the joint probability is relatively low. But even so, sharing can make all entities winners. It goes without saying that an economy's growth and development rest on the rate of growth of its (ignoring the role of foreign trade) technical knowledge. UI research linkages reinforce and enhance this rate. Apparently, the business world realizes the sharing principle. Since many joint research projects are financed by the government (at least in the US), the role of the government in reducing barriers to the formation of UI linkages and perhaps even the uncertainty involved should not be overlooked. The UI literature on its role has seemingly overlooked it, when it comes to reducing barriers to UI linkages.

One final consideration is the phenomenon of moral hazard (or in the context here, the free rider phenomenon). Since entities ideally freely share knowledge, moral hazard in our model's context would show up if one entity were not being diligent in its efforts to produce knowledge, in effect, relying on the other entity. If each entity's behavior is such that it assumes it will share in the other's success, then a prisoner's dilemma situation can arise, so that both entities lose. This is where the design and the administration of the organizational structure of the entities become important elements in the success of the sharing process as the literature has shown.

Acknowledgment The author would like to thank Methaya Monaiyapong for assistance with the references and the figures on earlier versions of the paper. Any errors or omissions are mine.

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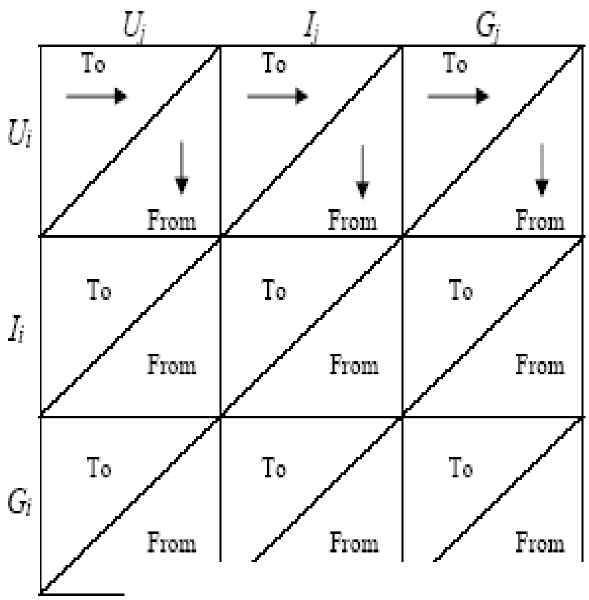

Fig. 1 Matrix of UIG linkages

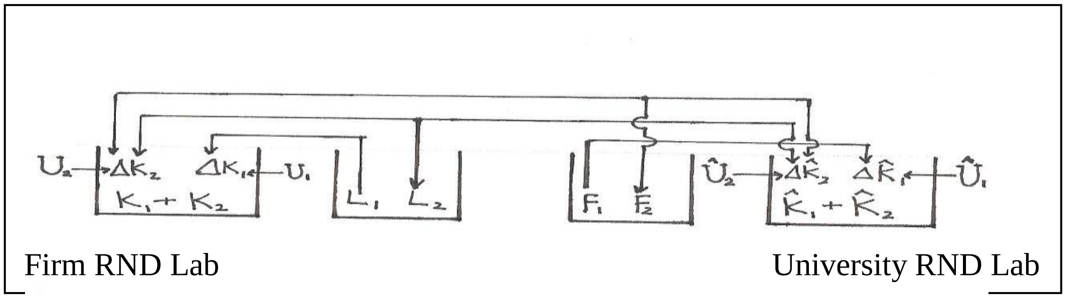

Fig. 2 Technical knowledge stocks and flows, Research personnel flows to and from sites, and Random shocks on knowledge flows

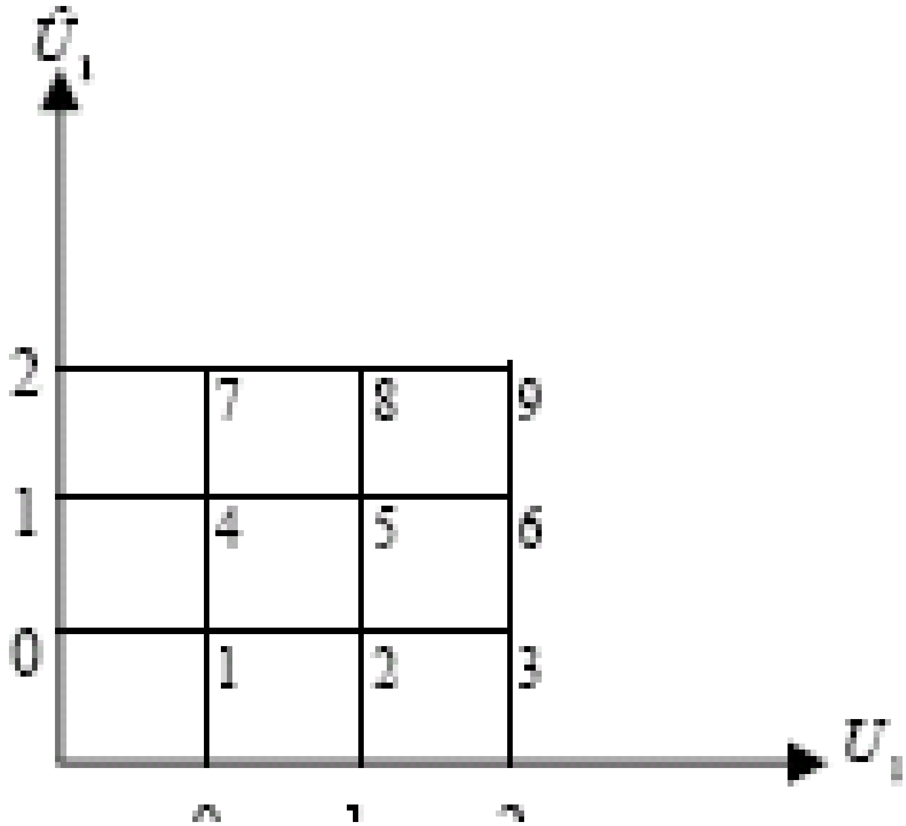

Fig. 3 Sample space

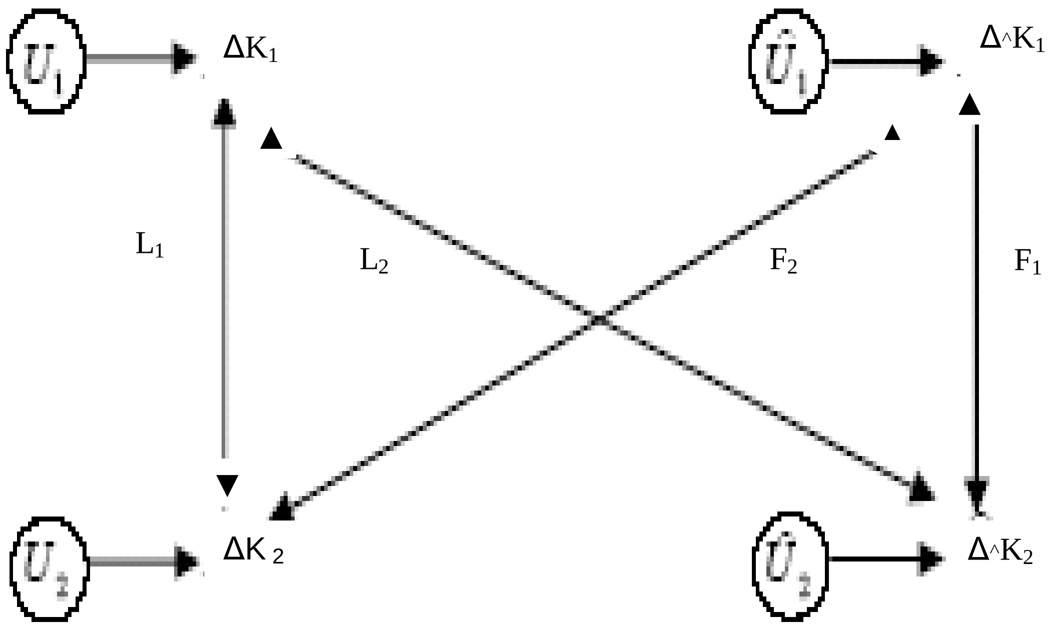

Fig. 4 Effects of random shocks suppressing all other effects