University-Industry R&D Collaboration Networks

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Abstract

Firms collaborate in the research and development stage prior to market competition to share knowledge about a cost-reducing technology. This paper extends the inter-firm R&D collaboration network by adding a university participant into the network and studies the incentives for the formation of university-industry network. The incentive-compatible network solutions are derived by solving a three-stage game. After carefully examining three different public spillover rates and substituting specific values to equilibrium solutions, the complete network is found to be pairwise stable when public spillover rate is weak to medium and the university-partial network when public spillover rate is strong to perfect. A conflict between pairwise stable network and efficient network is likely to occur when public spillover is medium. The conclusions reached provide some references to the firms and universities which want to enter the university-industry network.

Key Words: University-industry R&D collaboration, network, pairwise-stability, efficiency JEL Code:

1 Introduction

Because of the complexity of technology and the fact that innovation is costly and uncertain, firms have motivations to cooperate in the Research and Development of cost-reducing technologies. Besides the inter-firm R&D collaborations, the partnership of higher educational institutions with industry to commercialize the results of scientific and technological research is becoming increasingly important and prevalent. University-Industry collaboration brings benefits to both sides. On the one hand, university research departments receive industry guidance from firms and promote the commercialization of new technologies; on the other hand, cost-shared R&D enhances firms ability to leverage its limited research funding with other firms and organizations, and to generate competitive advantages.

Universities are now part of the systems of innovation spanning the globe. Universities' involvement in industrial projects in Europe has a long history. Schwerin (2004) details how in Scotland the construction of the improved steam engine by Glasgow University's instrument maker James Watt in 1765 was soon applied to factory steam engines and later facilitated the construction of steamships. In 19th century Britain universities were also involved in actions to improve public health in growing and insalubrious towns and cities as well as safety and working conditions in mines and factories. German universities also undertook research largely directed by industry, especially the chemical industry. Since the 1970s the United States government has aggressively promoted the alignment of university and industrial researchers through specific funding programs. In both Europe and the US the rapid rise of the chemical and pharmaceutical industries was associated with successful collaboration with academic scientists. In Japan, the promotion of university-industry collaboration is a core part of the Second Science and Technology Basic Plan[1]. Systemic reforms to promote relationships between universities and public research institutions and private companies in the field of R&D are being rapidly implemented.

Before introducing the model of university-industry collaboration network, it is worthwhile to review some of the literature on university-industry interactions.

While there is nothing new in universities bilateral links with industry, it is quite recent to apply the network theory to simulate the R&D collaboration networks between firms and universities.

Jackson & Wolinsky (1996) proposed the notion for pairwise stability and efficiency of social and economic networks.

A great number of researches have focused on the pairwise stability and efficiency of various kinds of networks. Goyal & Moraga-González (2001) have analyzed the incentives for R&D collaborations between horizontally related firms [2] when governments cannot subsidize R&D, in which they have basically shown that a conflict between the incentives of firms to collaborate and social welfare is likely to occur, and will arise if public spillovers from research are not too small.

[1] The Second Science and Technology Basic Plan outlines the basic direction of the nation's science and technology policies for the period spanning 2001 to 2006 and presents a strong argument for the need to revamp Japan's innovation system to encourage companies to become more innovative.

[2] Horizontally related firms exhibit some degree of market rivalry. Many markets are characterized by a high level of inter-firm collaboration in R&D activity. A significant proportion of such collaboration takes place between horizontally related firms.

Song & Vannetelbosch (2007) reconsider the Goyal & Moraga-González (2001) model of strategic networks in order to analyze how government policies, such as subsidies, will affect the stability and efficiency of networks of R&D collaboration among three firms located in different countries. A conflict between stability and efficiency is likely to occur. When governments cannot subsidize R&D, this conflict will occur if public spillovers are not very small. However, when governments can subsidize R&D, the likelihood of a conflict is considerably reduced. Indeed, a conflict will arise only if public spillovers are very small or very large.

Goyal & Joshi (2002) find that incentives to form links are intimately related to the nature of market competition. Their analysis of networks in oligopoly suggests that collaborations are used by firms to generate competitive advantage and that strategically stable networks are often asymmetric, with some firms having many links while others have few links or are isolated.

Zikos (2010) develops a model of endogenous network formation in order to examine the incentives for R&D collaborations in mixed oligopoly. The State-owned enterprise is found to be used as policy instruments in tackling the potential conflict between individual and collective incentives for R&D collaboration.

Motivated by both universities' active participation in industrial links and recent trends in R&D partnering activity, this paper develops a model of university-industry R&D collaboration network formation to study the incentives for bilateral collaborations. According to Petruzzelli & Messeni (2009), universities and firms belonging to similar cultural contexts are more able to achieve better innovative outcomes. Thus the firms and university in the model locates in the same country.The paper aims to investigate the role of a profit-maximizing university in influencing the structure of collaborations, and the potential implications this might have on the industry structure and performance. In particular, the paper primarily focuses on the following questions:

(1) *What are the incentives of competing firms that pursue efficiency-enhancing innovations to establish collaborative alliances? What is the architecture of the incentive-compatible networks?*

(2) *How does the presence of a non-competing university affect the structure of the incentive-compatible networks; and, are individual incentives to form collaborations adequate from a social welfare point of view?*

To answer these questions, the paper considers an oligopoly with two competing firms collaborating with a university in R&D prior to competing in the product market. In the first stage, the three agents form pairwise collaboration links [3] for the purpose of sharing knowledge on a cost reducing technology within the context of joint research projects. In the second stage, firms and the university independently and simultaneously choose a level of R&D effort. The selection of R&D efforts, together with the mode of knowledge spillovers, and the type of research network which is decided in the first stage, determine the effective production costs. Finally, firms compete in the market of a homogeneous good by setting quantities.

The paper is organized in following manner. The model is presented in Section 2. Section 3 solves the network formation process by backward induction. Section 4 analyzes the

[3] A collaboration link is interpreted as technological partnership which is costly but helps lower costs of production of the firms involved.

stability and efficiency of university-industry R&D networks, and comments on the conflict between stability and efficiency of networks. Section 5 concludes.

2 The Model

The model setup is as follows: two competing firms and a university form pairwise collaboration links to develop a new technology that enhances productive efficiency, and hence, lowers costs. The two firms then compete in the product market. The paper will focus on the incentive for R&D collaborations, and make comparisons between stable and efficient networks. The next subsection first develops the required terminology and introduce some definitions.

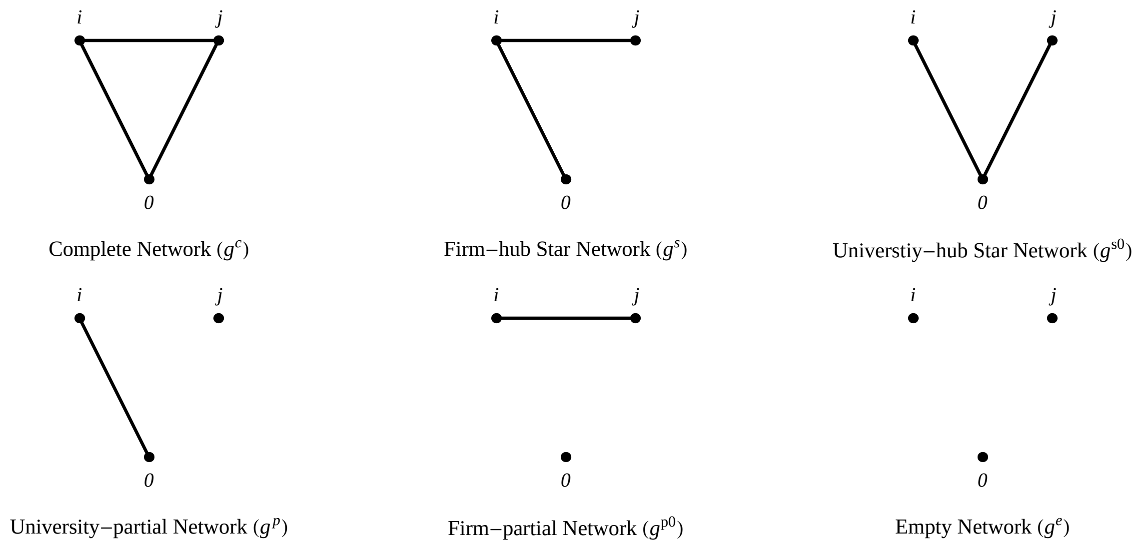
2.1 Networks

The set of participants of the collaboration network is denoted by $N = \{0, 1, 2\}$. The set comprises a university (indexed by $i = 0$) which maximizes its own profit and 2 identical private firms. The firms produce homogeneous goods and compete in the market by setting quantity (Cournot competition). Let $q_i (i = 1, 2)$ denote the quantities of goods produced by the firms, and the aggregate quantity on the market is $Q \equiv \sum_{i=1,2} q_i$. The inverse demand function is $P(Q) = a - Q$, for $0 \leq Q < a$; and $P(Q) = 0$, otherwise. A network is denoted by g under which the link between any two members of N, i and j, is simply denoted by $ij \in g$. This implies participants i and j maintain a collaboration link under network g. In any network g, nodes represent firms or university and each link represents a pairwise R&D collaboration. Firms can add or sever a link from a given network if it brings benefits to them[4]. We write $g + ij$ for adding a new link to the existing network g, and similarly $g - ij$ for severing the link between i and j. We say there is a *path* between two participants if and only if there exists a sequence of firms $i_1, , i_k$ such that $i_k i_{k+1} \in g$ for each $k \in 1, , k - 1$ with $i_1 = i$ and $i_k = j$. Let $N_i(g)$ be the set of firms that have a collaboration link with firm i in network g, and let G be the set of all possible networks.

With the involvement of the university, most of the networks in the paper are asymmetric. In this model set-up, there are six possible networks: (i) the complete network, g^c, in which all participants maintains a collaboration link with each other; (ii) the star network, in which one participant ("hub") is connected to the other two ("spokes"), but the latter remain disconnected. There are two cases to be distinguished here: either one of the firm or the university can be a hub. The firm-hub star network is called g^s, and the university-hub star network, g^{s0}; (iii) The partially connected networks, in which two participants are connected and the third is isolated, also have two cases: the university-partial network in which one of the firm is isolated is called g^p, and the firm-partial network in which the university is isolated, g^{p0}; (iv) the empty network, g^e, in which there are no collaboration links. The six possible network structures are presented in Figure 1.

[4]While a link can be severed unilaterally, forming a link is a bilateral decision, i.e. a link is formed if and only if the two firms involved agree to form the link.

Figure 1: Six Possible Network Structures



2.2 R&D Effort and Spillovers

Given a network g, every participant i independently chooses an R&D effort level x_i. R&D effort helps lower firm's marginal cost, but it is costly with the cost represented by the quadratic function $\Gamma(x_i) = \gamma x_i^2, \gamma > 0$. This implies the diminishing returns to the level of R&D effort x_i. For simplicity, assume $\gamma = 1$, which ensures non-negativity of all variables. The effective level of R&D is the total reduction in a firm's marginal cost and it comes from two parts: its own research effort x_i and the research effort of other participants. In order to model effective R&D, assume that the spillover rate is exogenously given as $\beta, \beta \in (0, 1]$. Assume that the spillover rate depends on the distance among the collaborating participants. Similar to Mauleon *et al.* (2008), the distance between two firms i and j is specified by the number of links in the shortest path between them, denoted by t_{ij}, and $t_{ij} = \infty$ if there is no path between them. The spillover rate has an inverse relationship with the distance of the two participants. This definition provides a clear distinction between direct and indirect R&D relationship. Spillover rate between direct collaborations ($t_{ij} = 1$) are always larger than those between indirect ones. Hence, given a network g and a set of R&D efforts $x_i(g)$, effective level of R&D for a firm is represented by the following formula:

$$X_i \equiv x_i + \beta(\frac{x_j}{t_{ij}} + \frac{x_0}{t_{i0}}), i \neq j, i, j \in \{1, 2\} \tag{1}$$

Firm i's marginal cost depends on its level of effective R&D, X_i, and structure of the relevant network. The marginal cost of production for each firm is represented by

$$c_i(g) = \bar{c} - x_i(g) - \beta(\frac{x_j(g)}{t_{ij}} + \frac{x_0(g)}{t_{i0}}), i \neq j, i, j \in \{1, 2\} \tag{2}$$

where $\bar{c}$ is firm's marginal cost without any R&D effort and collaboration.

2.3 Payoffs

Besides total production cost, the firm also incurs an R&D effort cost. Thus, the profit of firm i in a collaboration network g is given by

$$\pi_i(g) = (a - Q - c_i(g))q_i(g) - x_i^2(g) \tag{3}$$

For the university, it only incurs the R&D effort cost and its cost function is similar to the firm's cost function in quadratic form.

$$C_0(g) = x_0^2(g) \tag{4}$$

Universities gain profits indirectly from commercializing R&D effort[5] at a commercializing rate of θ [6]. In order to focus on the incentives of strategic R&D alliances, the model does not consider the transfers between the university and collaborating firms. Instead, the profit of the university relates to its own R&D effort, and collaborated firms R&D effort level. The structure of the profit function shows that the output of the university R&D effort is enlarged by the collaborating firms' effort at a rate of θ. The function is shown below:

$$\pi_0(g) = \theta\beta(\frac{x_i(g)}{t_{i0}} + \frac{x_j(g)}{t_{j0}})x_0(g) - x_0^2(g) \tag{5}$$

For any network g, the government maximizes the social welfare. Let $W(g)$ denote the social welfare of the country which consists of all agents' profits and consumer surplus.

$$W(g) = \frac{Q^2(g)}{2} + \sum_{i=0}^{2} \pi_i(g) \tag{6}$$

2.4 The Timing of Moves

The firms and the university interact in a three-stage game. In the first stage, participants form pairwise collaboration links. Assume that the formation of links requires no additional costs for the parties involved Goyal & Moraga-González (2001). In the second stage, the participants choose simultaneously and independently their level of R&D effort. Finally, firms compete in the product market by setting quantities. The university does not involve in the final stage. To solve this multi-stage game, first obtain the equilibrium solutions of the last two stages by backward induction. Then turn to stage one and apply the notions of pairwise stability to obtain the pairwise stable network.

With involvement of a non-competing university, the network formation process becomes much more complicated, especially in the case of asymmetric networks, i.e. star networks and partial networks. In some situations, the closed form solutions are very complicated.

[5]Profits from commercializing of R&D come in various forms, like patents, license etc.

[6]There are three possible ways to model the profit function of the university in the R&D collaboration network: (i) The university exerts an R&D effort level and gets profits from its research results. The university benefits from collaborating firms by spillovers. This way of modelling university profit is adopted in the paper. (ii) The university extracts some percent of profits from the collaborating firms. (iii) The university spins off and produces products itself.

Therefore, the pairwise stable networks are found by restricting attention to strategic alliances that emerge for five given values of the spillover parameters (Song & Vannetelbosch, 2007), namely (i) weak spillovers, $\beta = 1/4$, (ii) moderate spillovers, $\beta = 1/2$, (iii) medium spillovers, $\beta = 5/8$, (iv) strong spillovers, $\beta = 3/4$,(v) perfect spillovers, $\beta = 1$.

3 Network Formation

This section investigates the firm's incentives to form bilateral collaborations in order to exchange knowledge on a cost reducing technology. Given the network structure, first derive the subgame perfect equilibrium of the last two stages. To illustrate the process, the complete network is solved as follows. The equilibrium solutions of the rest of the network structures are shown in the Appendix.

3.1 Complete Network

The marginal cost for each firm under network g^c is

$$c_i(g^c) = \bar{c} - x_i - \beta x_0 - \beta x_j, i \neq j, i, j \in \{1, 2\} \tag{7}$$

Substitute the cost functions (7) into profit function (3) and get the equilibrium quantity of the Cournot competition stage game as:

$$q_i(x_0, x_i, x_j) = \frac{1}{3}(a - \bar{c} + (2 - \beta)x_i + \beta x_0 + (2\beta - 1)x_j) \tag{8}$$

In the second stage, university and firms decide on the most profitable R&D effort level. The profit function for the firm can be obtained by substituting the Cournot equilibrium quantities (8) into profit function (3).

The university's profit function under complete network turns out to be:

$$\pi_0(g^c) = \theta\beta(x_i(g^c) + x_j(g^c))x_0(g^c) - x_0^2(g^c) \tag{9}$$

After getting the equilibrium R&D effort levels for all agents, substituting that into equations (8),(3),(6) to get equilibrium quantities, profits and social welfare functions under complete network. The results are shown in Table 1.

4 Pair-wise Stability and Efficiency of Network

4.1 Pairwise Stability

The stable network can be found by comparing with the other adjacent networks [7]. The stability of the network ensures that agents do not benefit from altering the structure of the network. The notion of the pairwise stability is proposed by Jackson & Wolinsky (1996). A network is pairwise stable if no agent benefits from severing one of their links and no other

[7] Adjacent networks: g' is adjacent to g if $g' = g + ij$ or $g' = g - ij$ for some ij

Table 1: Equilibrium Solutions Under Complete Network

University	**Firm**
$x_0(g^c) = \dfrac{(2-\beta)\beta\theta(a-\bar{c})}{\beta^3\theta+\beta^2(1-2\theta)-\beta+7}$	$x_i(g^c) = \dfrac{(2-\beta)(a-\bar{c})}{\beta^3\theta+\beta^2(1-2\theta)-\beta+7}$
	$q_i(g^c) = \dfrac{3(a-\bar{c})}{\beta^3\theta+\beta^2(1-2\theta)-\beta+7}$
$\pi_0(g^c) = \dfrac{(\beta-2)^2\beta^2\theta^2(a-\bar{c})^2}{\left(\beta^3\theta+\beta^2(1-2\theta)-\beta+7\right)^2}$	$\pi_i(g^c) = \dfrac{\left(-\beta^2+4\beta+5\right)(a-\bar{c})^2}{\left(\beta^3\theta+\beta^2(1-2\theta)-\beta+7\right)^2}$
$W(g^c) = \dfrac{\left(\beta^4\theta^2-4\beta^3\theta^2+\beta^2\left(4\theta^2-2\right)+8\beta+28\right)(a-\bar{c})^2}{\left(\beta^3\theta+\beta^2(1-2\theta)-\beta+7\right)^2}$	

two agents benefit from adding a link between them, with one benefiting strictly and the other at least weakly. The definition is presented more strictly as follows:

Definition : A network is pairwise stable if

(i) $\forall ij \in g, \pi_i(g) \geq \pi_i(g-ij)$ and $\pi_j(g) \geq \pi_j(g-ij)$

(ii) $\forall ij \notin g$, if $\pi_i(g) < \pi_i(g+ij)$, then $\pi_j(g) > \pi_j(g+ij)$

Condition (i) implies that for any pair in network g, there is no incentive to delete existing link and condition (ii) ensures that there is no incentive to form new link either. This definition illustrates that a stable network will not be defeated [8] by its adjacent networks. It also implies that while it is bilateral to form a new link so that both agents of the new link are better off than not linked with at least one agent benefits strictly, it is unilateral to sever a link as long as one agent can benefit from deleting the link.

In order to analyse the stability of networks, construct four situations in which public spillover rate is assigned different numbers, namely, (i)weak spillovers, $\beta = 1/4$, (ii) medium spillovers, $\beta = 1/2$, (iii) strong spillovers, $\beta = 3/4$, (iv) perfect spillovers, $\beta = 1$. Besides, assume that the university's commercializing rate $\theta = 2$. This means the university can generate revenue twice as much as the product of its own R&D effort level and the effort spillover. This assumption is moderate and can generate reasonable results to help analysing the stability of the network more directly. Substituting the numbers into the equilibrium solutions of different types of networks leads to the results in Table 2. Some important results for the university-industry network can be drawn.

(i) The complete network is pairwise stable when public spillover is weak ($\beta = 1/4$), moderate ($\beta = 1/2$) or medium ($\beta = 5/8$);

(ii)when public spillover is is strong ($\beta = 3/4$) or perfect ($\beta = 1$), the university-hub network is pairwise stable;

(iii) The empty network, the university-hub star network and the partial networks are never pairwise stable.

[8] A network g' defeats g either if $g' = g - ij$ and $\pi_i(g') \geq \pi_i(g)$ or if $g' = g + ij, \pi_i(g') \geq \pi_i(g)$ and $\pi_j(g') \geq \pi_j(g)$ with at least one inequality holding strictly.

Table 2: Participants' Profits under Different Networks and Spillover Rates

		g^c	g^s	g^{s0}	g^p	g^{p0}	g^e
	π_i	$0.137(a-\bar{c})^2$	$0.139(a-\bar{c})^2$	$0.124(a-\bar{c})^2$	$0.092(a-\bar{c})^2$	$0.128(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
$\beta=\frac{1}{4}$	π_j	$0.137(a-\bar{c})^2$	$0.126(a-\bar{c})^2$	$0.124(a-\bar{c})^2$	$0.116(a-\bar{c})^2$	$0.128(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
	π_0	$0.018(a-\bar{c})^2$	$0.010(a-\bar{c})^2$	$0.020(a-\bar{c})^2$	$0.005(a-\bar{c})^2$	0	0
	π_i	$0.188(a-\bar{c})^2$	$0.191(a-\bar{c})^2$	$0.168(a-\bar{c})^2$	$0.069(a-\bar{c})^2$	$0.148(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
$\beta=\frac{1}{2}$	π_j	$0.188(a-\bar{c})^2$	$0.148(a-\bar{c})^2$	$0.168(a-\bar{c})^2$	$0.156(a-\bar{c})^2$	$0.148(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
	π_0	$0.063(a-\bar{c})^2$	$0.033(a-\bar{c})^2$	$0.087(a-\bar{c})^2$	$0.014(a-\bar{c})^2$	0	0
	π_i	$0.219(a-\bar{c})^2$	$0.221(a-\bar{c})^2$	$0.206(a-\bar{c})^2$	$0.057(a-\bar{c})^2$	$0.155(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
$\beta=\frac{5}{8}$	π_j	$0.219(a-\bar{c})^2$	$0.158(a-\bar{c})^2$	$0.206(a-\bar{c})^2$	$0.182(a-\bar{c})^2$	$0.155(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
	π_0	$0.091(a-\bar{c})^2$	$0.046(a-\bar{c})^2$	$0.149(a-\bar{c})^2$	$0.018(a-\bar{c})^2$	0	0
	π_i	$0.254(a-\bar{c})^2$	$0.251(a-\bar{c})^2$	$0.261(a-\bar{c})^2$	$0.046(a-\bar{c})^2$	$0.160(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
$\beta=\frac{3}{4}$	π_j	$0.254(a-\bar{c})^2$	$0.167(a-\bar{c})^2$	$0.261(a-\bar{c})^2$	$0.210(a-\bar{c})^2$	$0.160(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
	π_0	$0.120(a-\bar{c})^2$	$0.059(a-\bar{c})^2$	$0.244(a-\bar{c})^2$	$0.021(a-\bar{c})^2$	0	0
	π_i	$0.32(a-\bar{c})^2$	$0.301(a-\bar{c})^2$	$0.48(a-\bar{c})^2$	$0.030(a-\bar{c})^2$	$0.163(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
$\beta=1$	π_j	$0.32(a-\bar{c})^2$	$0.178(a-\bar{c})^2$	$0.48(a-\bar{c})^2$	$0.266(a-\bar{c})^2$	$0.163(a-\bar{c})^2$	$0.102(a-\bar{c})^2$
	π_0	$0.16(a-\bar{c})^2$	$0.072(a-\bar{c})^2$	$0.64(a-\bar{c})^2$	$0.024(a-\bar{c})^2$	0	0

To briefly prove these observations, notice that, first, when public spillover is weak ($\beta = 1/4$), moderate ($\beta = 1/2$) or medium ($\beta = 5/8$), $\pi_i(g^c) > \pi_i(g^{s0})$ and $\pi_j(g^c) > \pi_j(g^{s0})$ with $ij \in g^c$ and $ij \notin g^{s0}$. Also, $\pi_j(g^c) > \pi_j(g^s)$ and $\pi_0(g^c) > \pi_0(g^s)$ with $j0 \in g^c$ and $j0 \notin g^s$. This means neither pair of firms i and j, nor pair of one firm and the university has incentives to delete their link in the complete network. The complete network is pairwise stable.

Second, when $\beta = 3/4$ or $\beta = 1$, the university-hub star network is pairwise stable when public spillover is strong or perfect, since no participants have incentives to form new links ($\pi_i(g^{s0}) > \pi_i(g^c)$ and $\pi_j(g^{s0}) > \pi_j(g^c)$) or delete existing links($\pi_0(g^{s0}) > \pi_0(g^p)$ and $\pi_j(g^{s0}) > \pi_j(g^p)$).

Third, the empty network is never pairwise stable, because $\pi_i(g^{p0}) > \pi_i(g^e)$ and $\pi_j(g^{p0}) > \pi_j(g^e)$ with $ij \in g^p$. At all levels of spillover rate, the empty network is always defeated by the firm-partial network in which two firms collaborate with each other. Likewise, the firm-hub star network is defeated by the complete network, the university-partial network by university-hub network, firm-partial network by firm-hub network. Hence, these four networks are not pairwise stable at all parameter values.

This result is consistent with common sense. When public spillover is weak to medium, both firms and the university tend to collaborate in R&D, since they can not only benefit from collaborating participants, but also have a relatively low risk of leakage. When spillover rate gets larger, the risk gets larger for a firm to collaborate with another firm. However, the university is not influenced by this risk since it does not involve in the market competition. Thus, university-hub network becomes the pairwise stable network when public spillover rate is strong or perfect. In this structure, maximum level of cooperation could be reached and also having the university as a hub reduces direct leakage between firms. The empty network is never pairwise stable for the firms and the university all have incentives to collaborate in R&D.

4.2 Efficiency

We can say that a network $g \in G$ is strongly efficient if $W(g) \geq W(g')$, for all $g' \in G$. The social welfare under different network and spillover rates can be easily computed and it can be observed that:

(i) When public spillover is weak ($\beta = 1/4$) or moderate ($\beta = 1/2$), the complete network is strongly efficient;

(ii) When public spillover is medium ($\beta = 5/8$), strong ($\beta = 3/4$) or perfect ($\beta = 1$), the university-hub network is strongly efficient.

The results in Table 3 shows that when public spillover gets larger, social welfare increases under all the networks except for the firm-partial and empty networks and also the university-hub network gradually outperforms the complete network. Hence, in case of high spillover rate, the network structure that allows some collaboration, but reduces direct interactions between competing firms would be more efficient. In general, collaboration brings benefit to the society, since higher spillover implies higher transmission of effective R&D level, which results in a substantial reduction in marginal cost. However, there is also exception in the case when only the two firms are directly related and public spillover is perfect, social welfare turns down.

Table 3: Social Welfare under Different Networks

		g^c	g^s	g^{s0}	g^p	g^{p0}	g^e
$\beta = \frac{1}{4}$	W	$0.705(a-\bar{c})^2$	$0.684(a-\bar{c})^2$	$0.674(a-\bar{c})^2$	$0.597(a-\bar{c})^2$	$0.644(a-\bar{c})^2$	$0.571(a-\bar{c})^2$
$\beta = \frac{1}{2}$	W	$0.938(a-\bar{c})^2$	$0.843(a-\bar{c})^2$	$0.934(a-\bar{c})^2$	$0.670(a-\bar{c})^2$	$0.691(a-\bar{c})^2$	$0.571(a-\bar{c})^2$
$\beta = \frac{5}{8}$	W	$1.086(a-\bar{c})^2$	$0.930(a-\bar{c})^2$	$1.163(a-\bar{c})^2$	$0.719(a-\bar{c})^2$	$0.704(a-\bar{c})^2$	$0.571(a-\bar{c})^2$
$\beta = \frac{3}{4}$	W	$1.245(a-\bar{c})^2$	$1.012(a-\bar{c})^2$	$1.504(a-\bar{c})^2$	$0.774(a-\bar{c})^2$	$0.708(a-\bar{c})^2$	$0.571(a-\bar{c})^2$
$\beta = 1$	W	$1.52(a-\bar{c})^2$	$1.122(a-\bar{c})^2$	$2.88(a-\bar{c})^2$	$0.888(a-\bar{c})^2$	$0.694(a-\bar{c})^2$	$0.571(a-\bar{c})^2$

4.3 Conflict Between Stability and Efficiency

The above observations show a conflict between pairwise stable network and efficient network when public spillover is medium. When public spillover is medium, the complete network is pairwise stable, but the university-hub star network is strongly efficient. The conflict do not exist when public spillover is small or very large (to perfect). This result is similar to Goyal & Moraga-González (2001) in which they have basically shown that a conflict between the incentives of firms to collaborate and social welfare is likely to occur, and will arise if public spillovers from research are not too small. But Song & Vannetelbosch (2007) shows that when governments can subsidize R&D, the likelihood of a conflict is considerably reduced. The university does not enter the third stage of market competition, but its involvement has a potential impact on the network structure. Both the pairwise stable network and efficient network turns from complete network to university-hub star network, but the process is slower for the pairwise stable network. That's why a conflict arises in the intermediate range. The university's effect on the network structure turns out to be similar to government intervention.

5 Conclusions

It is increasingly prevalent that universities involve in inter-firm R&D collaborations prior to market competitions. It is meaningful to study the role of a university in the incentives of network formation. This paper develops a simple model of network formation to examine the incentives of firms to form collaboration links with university. It shows the process of a three-stage network formation game and the results is that the complete network is pairwise stable when public spillover rate is small, but the university-hub star network is pairwise stable when the public spillover rate is large. The efficient network also turns from complete network to university-hub star network as spillover gets larger. A conflict between the stability and efficiency is likely to occur when public spillover rate is medium. University's role in the R&D collaboration network has similar effect to government intervention, which directs pairwise stable networks to socially efficient ones. The research in this topic can be extended in several aspects. For example, the university and firms can be located in different countries so that we examine the international R&D collaboration case. Furthermore, the government can intervene in the network formation process by announcing a R&D subsidy rate (tax if negative).

A Appendix

A.1 The Firm-hub Star network

Under the firm-hub star network, g^s, one firm is connected with the other firm and the university while the other two participant are disconnected. The equilibrium R&D effort, quantities and profits are shown in Table 4, but social welfare is not displayed due to complexity.

Table 4: Equilibrium Solution under Firm-hub Star Network

University(Spoke)
$x_0(g^s) = -\frac{6\beta\left(\beta^3-5\beta^2+5\beta+2\right)\theta(a-\bar{c})}{4\beta^5\theta+\beta^4(8-21\theta)+2\beta^3(9\theta-16)+8\beta^2(2\theta+9)-160\beta-56}$
$\pi_0(g^s) = \frac{36\beta^2\left(\beta^3-5\beta^2+5\beta+2\right)^2\theta^2(a-\bar{c})^2}{\left(4\beta^5\theta+\beta^4(8-21\theta)+2\beta^3(9\theta-16)+8\beta^2(2\theta+9)-160\beta-56\right)^2}$
Firm(Hub)
$x_i(g^s) = -\frac{(\beta-2)(a-\bar{c})\left(\beta^3\theta-2\beta^2(\theta-4)-24\beta-8\right)}{4\beta^5\theta+\beta^4(8-21\theta)+2\beta^3(9\theta-16)+8\beta^2(2\theta+9)-160\beta-56}$
$q_i(g^s) = \frac{3(a-\bar{c})\left(\beta^3\theta-2\beta^2(\theta-4)-24\beta-8\right)}{4\beta^5\theta+\beta^4(8-21\theta)+2\beta^3(9\theta-16)+8\beta^2(2\theta+9)-160\beta-56}$
$\pi_i(g^s) = -\frac{\left(\beta^2-4\beta-5\right)(a-\bar{c})^2\left(\beta^3(-\theta)+2\beta^2(\theta-4)+24\beta+8\right)^2}{\left(4\beta^5\theta+\beta^4(8-21\theta)+2\beta^3(9\theta-16)+8\beta^2(2\theta+9)-160\beta-56\right)^2}$
Firm(Spoke)
$x_j(g^s) = \frac{2(\beta-2)(a-\bar{c})\left(\beta^3\theta-2\beta^2(\theta+2)+12\beta+4\right)}{4\beta^5\theta+\beta^4(8-21\theta)+2\beta^3(9\theta-16)+8\beta^2(2\theta+9)-160\beta-56}$
$q_j(g^s) = -\frac{6(a-\bar{c})\left(\beta^3\theta-2\beta^2(\theta+2)+12\beta+4\right)}{4\beta^5\theta+\beta^4(8-21\theta)+2\beta^3(9\theta-16)+8\beta^2(2\theta+9)-160\beta-56}$
$\pi_j(g^s) = -\frac{4\left(\beta^2-4\beta-5\right)(a-\bar{c})^2\left(\beta^3\theta-2\beta^2(\theta+2)+12\beta+4\right)^2}{\left(4\beta^5\theta+\beta^4(8-21\theta)+2\beta^3(9\theta-16)+8\beta^2(2\theta+9)-160\beta-56\right)^2}$

A.2 The University-hub Star Network

Under the university-hub star network, g^{s0}, the university is connected with the two firms respectively and the two private firms are not connected. The equilibrium R&D effort, quantities, profits and social welfare are shown in Table 5.

Table 5: Equilibrium Solution under University-hub Star Network

University(Hub)	Firm(Spoke)
$x_0(g^{s0}) = \dfrac{2(4-\beta)\beta\theta(a-\bar{c})}{2\beta^3\theta+\beta^2(1-8\theta)-2\beta+28}$	$x_i(g^{s0}) = \dfrac{2(4-\beta)(a-\bar{c})}{2\beta^3\theta+\beta^2(1-8\theta)-2\beta+28}$
	$q_i(g^{s0}) = \dfrac{12(a-\bar{c})}{2\beta^3\theta+\beta^2(1-8\theta)-2\beta+28}$
$\pi_0(g^{s0}) = \dfrac{4(\beta-4)^2\beta^2\theta^2(a-\bar{c})^2}{\left(2\beta^3\theta+\beta^2(1-8\theta)-2\beta+28\right)^2}$	$\pi_i(g^{s0}) = \dfrac{4\left(-\beta^2+8\beta+20\right)(a-\bar{c})^2}{\left(2\beta^3\theta+\beta^2(1-8\theta)-2\beta+28\right)^2}$
$W(g^{s0}) = \dfrac{4(a-\bar{c})^2\left(\beta^4\theta^2-8\beta^3\theta^2+2\beta^2\left(8\theta^2-1\right)+16\beta+112\right)}{\left(2\beta^3\theta+\beta^2(1-8\theta)-2\beta+28\right)^2}$	

A.3 The University Partial Network

Under university partial network, g^p, the university is connected with one firm and the other firm is isolated. Results are shown in Table 6.

Table 6: Equilibrium Solution under University Partial Network

University(Linked)	Firm(Linked)	Firm(Isolated)
$x_0(g^p) = \dfrac{\beta,\theta,(a-\bar{c})}{3\beta^2\theta+7}$	$x_i(g^p) = \dfrac{2(a-\bar{c})}{3\beta^2\theta+7}$	$x_j(g^p) = \dfrac{2(a-\bar{c})\left(\beta^2\theta+1\right)}{3\beta^2\theta+7}$
	$q_i(g^p) = \dfrac{3(a-\bar{c})}{3\beta^2\theta+7}$	$q_j(g^p) = \dfrac{3(a-\bar{c})\left(\beta^2\theta+1\right)}{3\beta^2\theta+7}$
$\pi_0(g^p) = \dfrac{\beta^2\theta^2(a-\bar{c})^2}{\left(3\beta^2\theta+7\right)^2}$	$\pi_i(g^p) = \dfrac{5(a-\bar{c})^2}{\left(3\beta^2\theta+7\right)^2}$	$\pi_j(g^p) = \dfrac{5(a-\bar{c})^2\left(\beta^2\theta+1\right)^2}{\left(3\beta^2\theta+7\right)^2}$
$W(g^p) = \dfrac{(a-\bar{c})^2\left(\beta^4\theta^2(4\theta+19)+2\beta^2\theta,(3\theta+28)+56\right)}{2\left(3\beta^2\theta+7\right)^2}$		

A.4 The Firm Partial Network

Under the firm partial network, g^{p0}, the two private firms are connected while the university is isolated. The equilibrium R&D results are shown in Table 7.

Table 7: Equilibrium Solution under Firm Partial Network

University(Isolated)	**Firm(Linked)**
$x_0(g^{p0}) = 0$	$x_i(g^{p0}) = \dfrac{(2-\beta)(a-\bar{c})}{\beta^2-\beta+7}$
	$q_i(g^{p0}) = \dfrac{3(a-\bar{c})}{\beta^2-\beta+7}$
$\pi_0(g^{p0}) = 0$	$\pi_i(g^{p0}) = \dfrac{\left(-\beta^2+4\beta+5\right)(a-\bar{c})^2}{\left(\beta^2-\beta+7\right)^2}$
$W(g^{p0}) = \dfrac{2\left(-\beta^2+4\beta+14\right)(a-\bar{c})^2}{\left(\beta^2-\beta+7\right)^2}$	

A.5 The Empty Network

Under the empty network, g^e, no participants are connected. The equilibrium R&D effort, quantities, profits and social welfare are given in Table 8 and they do not vary with spillover rate.

Table 8: Equilibrium Solution under the Empty Network

University(Isolated)	**Firm(Linked)**
$x_0(g^e) = 0$	$x_i(g^e) = \dfrac{2(a-\bar{c})}{7}$
	$q_i(g^e) = \dfrac{3(a-\bar{c})}{7}$
$\pi_0(g^e) = 0$	$\pi_i(g^e) = \frac{5}{49}(a-\bar{c})^2$
$W(g^e) = \frac{4}{7}(a-\bar{c})^2$	

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