Benefits of co-operation on innovative performance: evidence from integrated circuits and biotechnology firms in the UK and Taiwan

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The increase of strategic alliance and national or pan-national government collaborative programmes has highlighted the shifting management and policy focus from inducing in-house R&D to promoting a joint partnership between firms and knowledge-generating organisations in the increasingly complex and costly innovation process. Both the 'dynamic capability' school and the 'innovation network' theorists demonstrate that inter-organisational co-operation has become a crucial mechanism for 'collective innovation'. However, little attempt has been undertaken to examine the relationship between inter-organisational co-operation and innovative performance at the firm level. The innovative activities and inter-organisational co-operation of integrated circuits and biotechnology sectors across Taiwan and the UK are investigated via a postal questionnaire survey. Multiple logistic regression models are deployed. The result reveals that the types of inter-organisational co-operation enhancing a firm's innovative performance vary across sectors and countries. Despite the variation, this paper argues that a firm's networking ability to co-operate with buyer firms, supplier firms and external organisations is becoming imperative for enhancing innovation in the increasingly distributed innovation process.

1. Introduction

Since the late 1980s the growth of inter-firm strategic alliances (Hagedoorn and Schakenraad, 1990; Hagedoorn, 1995), industry-university co-operation (Kenney, 1986; Stankiewicz, 1986; Howells *et al*., 1998), firm-R&D institution co-operation (Faulkner and Senker, 1995) and governmental collaborative programmes (e.g., US SEMATECH, EU Framework programmes and EUREKA) has highlighted that the world economy has been evolving into one that is both associational (Cooke and Morgan, 1998) and alliance-based (Dunning, 1997). The intensification of co-operation across organisational and national borders highlighted the need for organisations to create knowledge conjoining in an innovation process that is increasingly uncertain, complex and costly. However, the relationship between co-operation and innovative performance at the firm level is still unclear. Is the firm with specific inter-organisational co-operation more likely to innovate? If yes, who are the prominent partners? The research elaborated below therefore attempts to answer these questions.

2. Literature review

2.1. Driving forces for co-operation

Hagedoorn and Schakenraad (1990) identify the trend towards increasing inter-firm co-operation in the world's biotechnology, IT (information technology) and advanced material sectors. The increase of inter-firm co-operation could be attributed to the changing business and technological environment. These driving forces for co-operation are (1) escalating R&D costs, (2) shortening technology life cycles, (3) increasing complexity of technologies, and (4) globalisation of technologies and markets (Dodgson, 1993; Coombs *et al.*, 1996).

Firms that are involved in co-operative ventures benefit from the sharing of costs and from reductions in risk that are associated with the development of a new process or product. The shortening technology life cycle has raised pressure on firms to launch their products on time in the market. In the game of competing technologies, co-operation facilitates the formation of compatibility among technologies. Consequently, the market tends to select the winning technology while this technology becomes widely compatible and its adoption presents network externality (Katz and Shapiro, 1985). Given the growing complexity of technologies, even big firms seldom possess a comprehensive range of in-house capabilities and knowledge, so they require partnership to develop complex technology/product projects jointly (Coombs and Metcalfe, 1998). Whilst the motivation for co-operation varies between different modes of inter-firm agreements, co-operation is one of the best means of entering foreign markets, especially where trade barriers are high (Hagedoorn and Schakenraad, 1990). In considering the macro-economic environment for co-operation, Kitson and Michie (1998) suggest that firms tend to establish more co-operative agreements, while they face more fierce domestic and/or foreign competition and experience a rapid growth in the market.

Rosenberg (1990) challenges the concept of basic research as a public good. He argues that scientific information, despite being widely available, cannot become an input factor in the innovative activities of firms until they undertake their own in-house (basic) research. A firm's internal research allows it to absorb, evaluate, and utilise the scientific information outside its own boundaries (Cohen and Levinthal, 1990; Arora and Gambardella, 1994). The studies of Faulkner and Senker (1995) and Pavitt (1991) have shown that the most effective way to transfer technology from knowledge-generating organisations (i.e., universities and R&D institutions) to firms is to establish co-operative links between them. Thus, co-operation can be achieved through formal organisational arrangements or informal personal contacts.

2.2. Co-operation as a joint knowledge creation

In traditional transaction cost analysis (Williamson, 1975, 1985), the dichotomy between the market and hierarchy for industrial organisation seems to provide little analytical power to explain the governance of innovation in the emerging alliance-based economy (Chesnais, 1988; Coombs *et al.*, 1996). Even Williamson (1991) himself and other resource-based researchers (Penrose, 1959; Richardson, 1972) propose that the hybrid form or inter-organisational co-operation should be treated as the third governance of industrial organisation. Inter-organisational co-operation can be regarded as a jointly knowledge generating process between partners. This provides the theoretical starting point for a study of inter-organisational co-operation in its own right.

Given the importance of external co-operation, two related research streams have emerged, the 'dynamic capability' perspective, and 'innovation and network' research. First, the 'dynamic capability' school (Teece, 1986; Teece and Pisano, 1994) claims that firms need different capabilities ranging from research and design, manufacturing, marketing to after-sale service in order to profit from their innovations. The notion of *complementary assets* is crucial here. Not all the firms possess a full range of capabilities that are necessary for commercialising their innovations. The 'make or buy' decision in capability development is largely dependent on the technological path the firm chooses, competitive positions the firm locates, and routine process the firm organizes (Tidd *et al.*, 1997). Consequently, firms have to co-operate with other firms or organisations in order to access the requisite capabilities in a timely manner. In the dynamic capability perspective, inter-organisational co-operation is regarded not only as an exploitation of partners' complementary assets but also as an exploration of learning and knowledge creation processes. Co-operation provides a channel for learning via access to new cognitive frameworks, routines, institutional arrangements and cultures (Ciborra, 1991; Mody, 1993).

Second, the stream studying on co-operation can be called the 'innovation network' school. Inter-organisational co-operation can be viewed as value chain networks (Håkansson, 1987, 1989), innovation networks (DeBresson and Amesse, 1991; Mytelka, 1991; Pisano, 1991; Powell *et al.*, 1996) and social networks (Gulati, 1998; Gulati *et al.*, 2000). The value chain network researchers claim that the most advanced source of innovation is created within the networks (Håkansson, 1987, 1989). The firm cannot innovate in isolation (DeBresson and Amesse, 1991; Mytelka, 1991). They need to establish an effective innovation network of customers, suppliers, competitors, universities and research institutions, etc. Dedicated biotechnology firms (DBFs) demonstrate their innovativeness through the establishment of symbiotic relationships with large incumbent pharmaceutical firms in the USA (Pisano, 1991; Powell *et al.*, 1996). This symbiotic relationship represent a division of biotechnology innovation in which DBFs largely do R&D activities, then incumbent firms do manufacturing and marketing of biopharmaceutical products.

In the economic sociology lenses, Gulati (1998; Gulati *et al.*, 2000) in his thematic works of strategic alliance claims that the firm's social network or social embeddedness plays a key role in influencing the firm's perception of availability and access of alliance. The prior social networks of firms influence their subsequent actions on formation, conduct and performance of strategic alliance. The social network research provides an insight that the benefits and performance of alliance on firms could be largely determined by the endowment of network resources and their positions in the networks (e.g., centrality, cliques).

2.3. The inter-organisational co-operation and innovative performance

In studying small and medium-sized enterprises (SMEs) in the UK, Rothwell (1991) finds that those SMEs innovating successfully tend to have dense external networks involving other firms, universities and research institutions. Niosi (2000) argues that Canadian DBFs having inter-firm alliance with foreign pharmaceutical firms enjoy rapid growth in terms of sales and employment.

Kitson and Michie (1998) find the firms that introduce technological innovation are more likely to establish partnerships for all technological, market and organizational reasons compared to the firms do not. Based on a survey of firms located in the UK's West Midlands, De Propris (2000) finds that firms that co-operate with buyers and suppliers tend to increase their ability to innovate. To investigate the relationship between co-operative arrangements and levels of innovation (incremental vs. radical), Tether (2002) and Fritsch and Lukas (2001) find that firms establishing external co-operation allow them to play the role of 'technology gatekeeper' in order to monitor external new knowledge and technology. Consequently, these firms involving in various kinds of co-operative arrangements are able to introduce the higher level of innovation, or radical innovation.

Despite the increasing importance of inter-organisational co-operation, the relationship between a firm's inter-organisational co-operation and its innovative performance remains under-researched. Most studies focus on inter-firm co-operation only (Kitson and Michie, 1998; De Propris, 2000; Niosi, 2000). This paper investigates inter-organisational co-operation in a broader sense and focuses upon relationships between firms and various kinds of knowledge generating organisations (firms, universities, R&D institutions, and governments). The purpose of the study is to examine how the firm's inter-organisational co-operative behaviour influences its chance to innovate.

2.4. Conceptual framework: the firm-centred networking approach

The study proposes a conceptual framework for examining the firm's inter-organisational co-operation. With a 'firm-centred' approach, the conceptual framework treats the firm as the centre of the co-operation network. The firm's inter-organisational co-operation therefore can be regarded as a set of linkages between various actors (i.e., firms and organisations).

The study investigates inter-organisational co-operation in the form of contract arrangements, strategic alliances and new organisation establishment. It implicitly considers informal co-operation such as personal contact association and group membership. With the social network perspective, this is important because informal contact is usually a pre-requisite condition for the further formal co-operation. Formal co-operation always blends formal organisational arrangements and prior informal personal relations or social embeddedness. Moreover, co-operation can take place in a range of activities including R&D, manufacturing and marketing, and after-sales' service. The framework is elaborated in the following sections.

2.4.1. Actors and types of co-operation. The study concerns three key types of inter-organisational co-operation: (1) inter-firm co-operation; (2) firm-research co-operation (e.g. universities and R&D institutions), and; (3) firm-government co-operation. Inter-firm co-operations are ela-borated into four kinds: (1) buyer firm co-operation; (2) supplier firm co-operation; (3) competitor firm co-operation; (4) 'other firm' co-operation.

2.4.2. Mechanisms. The study classifies three main mechanisms of inter-firm co-operation, which are derived from the concept of transactional cost economics (Williamson, 1975, 1985). One extreme mechanism is co-operation through 'contract arrangements' such as contract R&D, manufacturing, marketing, and licensing, where the knowledge transactions can be precisely priced. The other extreme mechanism of co-operation is 'establishing a new organisational form' such as equity investment, joint venture and merger and acquisition. Williamson (1985) names this as 'market' and the latter mechanism as 'hierarchy'. The third co-operative mechanism is 'strategic networking or alliance' where partners generate knowledge jointly. Joint R&D collaborations, research consortia, and co-development exercises are all treated as belonging in the category of 'strategic alliance'.

2.4.3. Strength. Measuring the strength of inter-organisation co-operation is mainly based on breadth rather than depth in the study. It is because the study assumes that the greater the number of organisations with which the firm co-operates, the more complementary assets (Teece, 1986) it will access in order to introduce new products and processes to the market. The strength of co-operation is considered in terms of the number of organisations or number of projects. On the other hand, each inter-organisational co-operation cannot be treated as homogenous in terms of quantity and quality of knowledge involved. Quantifying knowledge intensity in each co-operation is sometimes self-defeating because knowledge flows in co-operative activities are always context-dependent, subjective, and dependent largely upon tacit forms.

The number of co-operative organisations is used to measure the strength in inter-firm, firm-research and firm-government links. The study measures firm-government co-operation by asking about the firm's participation in government (often multi-ministry) Research, Technology and Development (RTD) projects.

Three hypotheses are derived from the above literature review and formulated as follows:

H1: *Firms co-operating with more firms are more likely to introduce technological innovation.*
H2: *Firms co-operating with more universities and R&D institutions are more likely to introduce technological innovation.*
H3: *Firms participating in more government-initiated research projects are more likely to introduce technological innovation.*

3. Methodology

3.1. A focus on technological innovation

The study examines the technological innovation of firms and this includes both product and process innovation. The details of product innovation and process innovation are examined. Research and development intensity (R&D expenditure divided by turnover) is used as a proxy for measuring R&D input of the firm.

The study adopts the view that technological innovations are 'new to firms' rather than 'new to market'. Technological innovation examined here includes imitated and adapted innovation (diffusion perspective) rather than a pure new product or process innovation in the market only.

3.2. Research method

Information regarding the firm's inter-organisational co-operation and innovative activities during 1996–98 was collected via postal questionnaires. All biotechnology firms and IC (integrated circuits) firms located in the UK and Taiwan were surveyed. The list of 96 UK biotechnology firms was collected mainly from *The UK Biotechnology Industry '96* (BioIndustry

Association, 1996). Ninety-two UK firms involved in IC design, manufacturing, packaging and testing are identified from various directories such as *European Electronics Directory* (Elservier Advanced Technology, 1996), *Profile of the Worldwide Semiconductor Industry* (Reed Electronic Research, 1997), *Electronics Component Manufacturing in the UK* (DTI, 1998), *KOMPASS UK 1999/2000* (Reed Research Organization, 1999) and *Overseas Companies Operating in Scotland* (Locate in Scotland, 1999). One hundred and forty IC firms and 72 biotechnology firms were collected from *Taiwan Semiconductor Yearbook 1999* and *Taiwan Biotechnology Industry 1998* respectively. In total, the research surveyed 400 IC and biotechnology firms across the UK and Taiwan. One hundred and sixty-two questionnaires were received. The overall response rate was 41%.

3.2.1. Scope of survey. The firms are dedicated to human pharmaceutical and veterinary products, medical contract research/manufacturing, materials and equipment supply, diagnostics (including drug delivery and rational drug design) and biotechnology-oriented chemicals are all considered as biotechnology firms in the research. The scope of survey includes the firms involved in IC design, manufacturing, packaging and testing.

3.2.2. Questionnaire design and pilot study. The questionnaire consists of seven sections, 20 questions in total and designed mostly by the author. Only the question investigating firm-central government co-operation, was borrowed from another source (UK Community Innovation Survey II, 1994–96). The questionnaires were sent to 20 randomly chosen firms for pre-testing. The wordings and structure of the questionnaires were improved through the pilot study of questionnaires.

3.2.3. Response rate. The questionnaires was mainly addressed to chief executive officers (CEO), or managing directors (MD) in the respondent companies. However, the study allows the recipients the freedom to pass the questionnaires on to other suitable persons to answer if s/he lacks specific knowledge. Several respondents noted that the required information had to be collated from multiple sources within the company because of the financial, human resource and technical information requested in the survey. Therefore, other senior managers within the company (e.g., operation managers or technical managers) offered final answers on some occasions.

Having conducted the second wave survey and telephone follow-up, the response rates were approaching 27% in the UK biotechnology sector, 29% in the UK IC sector, 15% in the Taiwan IC sector and 22% in the Taiwan biotechnology sector. Due to the small population, a separate questionnaire was sent to non-respondent firms. The proxy questionnaire was addressed to R&D managers/directors in order to increase the response rate. Finally the research gained 33 responses from the UK IC firms (a 36% response rate), 36 responses from the UK biotechnology firms (a 38% response rate), 60 responses from Taiwan IC firms (a 44% response rate), and 33 responses from the Taiwan biotechnology firms (a 49% response rate). In total, the survey gained 162 returns out of 400 firms with a 41% response rate. For details of response rate by sector refer to Table 1.

3.2.4. Non-response bias. Since mergers and acquisitions (M&A) were prevalent in the late-1990s, this caused response problems for those firms facing M&A deals. The exemplar in the UK biotechnology sector was Celltech merged with Chiroscience in 1999, then with Medeva in January 2000. The M&A activities also took place in the Taiwan IC sector. Two symbolic cases were the first and second largest Taiwanese IC firms, Taiwan Semiconductor Manufacturing Company (TSMC) and United Microelectronics Company (UMC). TSMC acquired domestic three IC firms (e.g., Vangard International) and UMC merged other independent IC firms into the company umbrella in 2000. Mitel, a Canadian

Table 1. Response rate by sector.

Sector	Population (A)	Number of responses (B)	Response rate (B/A) (%)
UK-IC	92	33	36
UK-biotechnology	96	36	38
Taiwan-IC	140	60	44
Taiwan-biotechnology	72	33	49
Total	400	162	41

telecommunication group acquired GSP (GEC Plessey Semiconductor), the last significant British chipmaker in 1998.

These firms were asked to answer the questionnaire depending on their respective stage of M&A. If they are in the pre-M&A stage, the study asks them to provide their original company information before the M&A arrangement, or the consolidated information if the M&A has been completed. Despite this, most of these firms still did not return the questionnaires, especially the firms that were being acquired. Moreover, the M&A agreement not only hinders responses among 'acquired' companies but also decreases the number of firms in the surveyed population. The result is possibly biased as a result of these firms undergoing pre- or post-merger activity.

3.3. Statistical analysis

3.3.1. Variables. The innovative activity is used as a dependent variable, a binary code. If a firm has introduced technological innovation during 1996–98, innovative activity variable INNO is coded to 1; otherwise, INNO is coded to 0. Independent variables include R&D intensity, the size of the firms, nationality, sector and three co-operation variables; altogether 7 variables in total. The dummy variables are applied to nationality of firms (UK and Taiwan) and sectors (IC and biotechnology). These co-operation variables are: (1) Inter_Firm, denotes co-operation with industrial partners (2) Firm_Res, denotes co-operation with universities and R&D institutions, and (3) Firm_Gov, denotes participation in government-initiated projects. Table 2 shows the definition of these variables.

3.3.2. Modelling strategy and logistic regression models. The study employs the full model (equation 1) to examine the relationship between co-operation variables and innovation performance. The 'enter' procedure is implemented. Due to the overall small respondent cases, the usual 0.05 criterion for statistical significance is relaxed to the 0.2 level which can still effectively identify significant predictors (Menard, 1995; Hosmer and Lemeshow, 1989; Hutcheson and Sofroniou, 1999). In other words, the study assumes that the *p*-value of the predictive variable is less than 0.2; then the variable could be significant enough to increase the firm's innovative performance.

In the full logistic regression model, three types of the co-operation, the R&D intensity (Inten-R&D) and number of employees (size) are used as independent variables to predict the firm's possibility of introducing technological innovation. The full *model* is as follows:

$$\begin{aligned}&\text{Logit (odds of introducing technological innovation)}\\&= \text{Logit (p)}\\&= b0 + b1 * \text{Inten\_R\&D} + b2 * \text{Size} + b3 * \text{Inter\_Firm}\\&\quad + b4 * \text{Firm\_Res} + b5 * \text{Firm\_Gov} \cdots \qquad (1)\end{aligned}$$

The paper runs the four sectors equation with nationality and sector dummies (UK vs. Taiwan, IC vs. biotech). To enhance the sample, the paper also runs two country equations by aggregating sectors and using a sector dummy (IC vs. biotech). By doing so, it helps to identify the prominent differences across sectors and nations.

The paper examines the following set of regressions: (1) a 4-sector regression with nation and sector dummies; (2) two country regressions

Table 2. Definitions of variables.

Variable	Definition	Measurement
Dependent variable		
INNO:	1 if firms introduce any technological innovation in 1996–1998; 0 otherwise	0 or 1
Predictive variables		
Inten_R&D:	R&D intensity (R&D expenditure/turnover)*100	Percentage
Size:	Number of Employees	Number of Employees
Nat:	Nationality (dummy variables applied)	UK = 0, Taiwan = 1
Sector:	Category of sectors (dummy variables applied)	IC = 0, Biotech = 1
Inter_Firm:	Number of firms co-operated with	Number of firms
Firm_Res:	Number of universities and R&D institutions co-operated with	Number of universities and R&D institutions
Firm_Gov:	Number of government R&D projects participated in	Number of projects

with sector dummy; and (3) four individual country-sector regressions. Firms could be innovative without participation in government projects in the real world. Moreover, the paper tests the above set of regressions with and without Firm_Gov in order to avoid the collinearity between co-operation variables shown in Table 4.

4. Results

4.1. Correlation

The Four-sector aggregation. There are 160 IC and biotechnology firms in the aggregated model. One hundred and fourteen out of 160 firms, with a share of 71% firms reported having introduced technological innovation during 1996–98. The average R&D intensity of four sectors is 26%. The average number of employees per firm is 428. In terms of co-operation types, each firm on average co-operates with 5.50 firms, 3.43 universities and R&D institutions, and participates in 0.98 government projects. The descriptive statistics and correlation matrix of four sectors are shown in Table 3.

Four sectors respectively. Twenty-five out of 34 *UK biotechnology* respondent firms, a share of 74%, reported introducing technological innovation during 1996–98. The average sector R&D intensity is 70%. The average number of employees per firm is 368 people in the sector. In terms of co-operation types, each firm on average co-operates with 9.09 firms, 6.59 universities and R&D institutions, and participates in two government projects.

Sixteen out of 33 *Taiwan biotechnology* respondent firms, a share of 48%, reported introducing technological innovation during 1996–98. The average sector R&D intensity is 11%. The average number of employees per firm is 91 people in the sector. In terms of co-operation types, each firm on average co-operates with 2.74 firms, 4.15 universities and R&D institutions, and participates in 0.88 government projects.

Twenty-two out of 33 the *UK IC* respondent firms, a share of 67%, reported introducing technological innovation during 1996–98. The average sector R&D intensity is 18%. The average number of employees per firm is 593 people in the sector. In terms of co-operation types, each firm on average co-operates with 8.39 firms, 3.30 universities and R&D institutions, and participates in 1.24 government projects.

Fifty-one out of sixty *Taiwan IC* respondent firms, a share of 85%, reported introducing technological innovation during 1996–98. The average sector R&D intensity is 14%. The average number of employees per firm is 561 people in the sector. In terms of co-operation types, each firm on average co-operates with 3.42 firms, 1.33 universities and R&D institutions, and participates in 0.30 government projects. The descriptive statistics of each sector is listed Table 4. In summary, the degree of the firm's inter-organizational links is influenced by both nation and sector. The UK IC and biotechnology firms tend to establish more inter-organizational links than Taiwanese firms do. Firms in the emerging biotechnology sectors tend to form more inter-organizational links than those in the relatively mature IC sectors.

4.2 The Logistic Regression Models

The Four-sector regression and nation regressions. In four-sector regression, the innovative performance between UK and Taiwanese firms is not robustly different (Table 5). However, IC firms introduced significantly more technological innovation than biotechnology firms during 1996–1998. Models 1&2 have consistently shown that the firm with a greater number of employees, more inter-firm cooperation and participating in more government projects is more likely to be

Table 3. Descriptive statistics and correlations (N = 160).

Variables	Mean	S. D.	1	2	3	4	5
1 INNO	.71	.45					
2 Inten_R&D	26%	93%	.12				
3 Size	428	1383	.15	−.03			
4 Inter_Firm	5.50	10.00	.18*	.03	.003		
5 Firm_Res	3.43	5.29	.12	.26**	.08	.36**	
6 Firm_Gov	.98	1.96	.17*	.12	.005	.47**	.43**

$^{**}p < 0.01$(two-tailed), $^{*}p < 0.05$.

Table 4. Descriptive statistics by sectors.

	UK Biotech (N = 34)		Taiwan Biotech (N = 33)		UK IC (N = 33)		Taiwan IC (N = 60)	
Variables	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1 INNO	.74	.45	.48	.51	.67	.48	.85	.36
2 Inten_R&D	70%	197%	11%	11%	18%	19%	14%	31%
3 Size	368	1663	91	108	593	2045	561	1131
4 Inter_Firm	9.09	10.84	2.74	4.59	8.39	15.90	3.42	5.87
5 Firm_Res	6.59	8.55	4.15	4.82	3.30	3.87	1.33	1.85
6 Firm_Gov	2.00	2.95	.88	.11	1.24	2.29	.30	.93

Table 5. The logistic regression models.

Variables	Model 1 Four sectors (N = 160)	Model 2 Four sectors (N = 160)	Model 3 UK sectors (N = 67)	Model 4 UK sectors (N = 67)	Model 5 Taiwan sectors (N = 93)	Model 6 Taiwan sectors (N = 93)	Model 7 UK bio (N = 34)
Intercept	−.11	.07	−1.755*	−.85	1.26*	1.29*	−4.59
Nat	.74$^{\Delta}$	.58					
Sector	−1.16	−1.05*	−.05	−.05	−2.16**	−2.09**	−.10
Inten_R&D	.000	.000	.000	.000	−.005	−.005	.04$^{\Delta}$
Size	.002$^{\Delta}$	.001$^{\Delta}$	.006$^{\Delta}$	.005	.001	.001	.43^{+}
Inter_Firm	.11^{+}	.11^{+}	.28*	.20*	.006	.01	−.21
Firm_Res	.07	.12$^{\Delta}$	.22$^{\Delta}$	.04	.24$^{\Delta}$	.24$^{\Delta}$	3.39$^{\Delta}$
Firm_Gov	.38^{+}		1.32*		.14		
OVERALL MODEL FIT							
-2 Log Likelihood	131.94	135.78	38.81	48.49	79.74	79.96	10.78
Model Chi-Square	20.20***	25.35***	25.39***	15.71**	16.87	16.65**	22.04**
Cox & Snell- R^2	.19	.17	.39	.26	.18	.18	.56
Nagelkerke- R^2	.28	.25	.55	.37	.27	.26	.79
Percent correct	72%	74%	83%	67%	76%	77%	89%

***$p<001$,**$p<.01$,*$p<.05$,$^{+}p<.1$,$^{\Delta}p<.2$ (Wald test). Nat dummy variable (UK = 0, Taiwan = 1), Sector dummy (IC = 0, biotech = 1)

Variables	Model 8 UK Bio (N = 34)	Model 9 UK IC (N = 33)	Model 10 UK IC (N = 33)	Model 11 Taiwan Bio (N = 33)	Model 12 Taiwan Bio (N = 33)	Model 13 Taiwan IC (N = 60)	Model 14 Taiwan IC (N = 60)
Intercept	−1.36	−1.96	−1.91	−.42	−.16	−1.616	−1.62
Nat							
Sector							
Inten_R&D	−.002	.07	.07	.07$^{\Delta}$	.06	.006	.006
Size	.02^{+}	.004	.004	.000	.000	.003$^{\Delta}$	.003$^{\Delta}$
Inter_Firm	.17	.31$^{\Delta}$	.31$^{\Delta}$	−.71^{+}	−.72^{+}	4.69	9.06
Firm_Res	.09	−.05	.006	.18	.20	12.06	12.36
Firm_Gov		.22		.23		7.30	
OVERALL MODEL FIT							
-2 Log Likelihood	24.18	19.90	19.96	29.52	29.87	13.82	13.82
Model Chi-Square	8.63^{+}	11.44*	11.39*	10.65^{+}	10.31*	31.80***	31.80***
Cox & Snell- R^2	.27	.37	.37	.31	.30	.44	.44
Nagelkerke- R^2	.39	.51	.51	.41	.40	.78	.78
Percent correct	78%	84%	84%	76%	72%	93%	93%

***$p<.001$,**$p<.01$,*$p<.05$,$^{+}p<.1$,$^{\Delta}p<.2$ (Wald test). Nat dummy variable (UK = 0, Taiwan = 1), Sector dummy (IC = 0, biotech = 1)

innovative. The firm-research links have only minor influence on the firm's innovative performance while firm-government cooperation is excluded (Model 2). The UK nation regression has shown that UK biotechnology firms do not introduce significantly more technological innovation than UK IC firms (Models 3&4). UK firms with more inter-firm co-operation and participating in more government projects are more likely to be innovative. The Taiwan nation regression reveals that Taiwanese IC firms are significantly more innovative than Taiwanese biotechnology firms (Models 5&6). Taiwanese firms that establish more co-operation with universities and R&D institutions will partially increase their innovative performance. The positive correlation between firm-government links and innovative performance is found in the four-sector regression and the UK nation regression, while Taiwanese firms participating in more government projects do not significantly increase their innovation performance.

Four sectors respectively. The coefficients of Size, Inter_Firm and Firm_Gov variables are statistically significant and both positive in Model 7. It shows that UK biotechnology firms with more employees and inter-firm links and participating in more government R&D projects will partially increase their possibility of introducing technological innovation.

Models 9&10 robustly indicate that UK IC firms with more inter-firm co-operation are more likely to innovate.

No inter-organizational links have significantly increased innovative performance in Taiwanese biotechnology firms except inter-firm co-operation (Models 11&12). Among all models, the only significantly negative relationship between inter-firm co-operation and innovative performance is identified in the Taiwan biotechnology sector. In other words, Taiwanese biotechnology firms with more inter-firm links will partially *reduce* the possibility of introducing technology innovation.

Only the coefficient of Size variable is at the significant level $p < 0.20$ in Models 13&14. The coefficient of Size is positive, which means that the bigger the firm size will partially increase the firm's possibility of introducing technological innovation in the Taiwan IC sector.

5. Discussion

5.1. *The importance of inter-firm co-operation for innovation*

The study finds that the firms having inter-firm co-operation are more likely to innovate in the four-sector regressions, the UK nation regression, the UK biotechnology sector, and the UK IC sector. This result is consistent with the studies of De Propris (2000) and Kitson and Michie (1998).

Interestingly, there is an exceptional sector, the Taiwan biotechnology sector where inter-firm co-operation could *decrease* the firm's innovative performance. It was possibly attributed that about half of Taiwanese established firms and DBFs just entered biotechnology business since 1997, and most were still in the R&D stage (DCB, 2000). One of the best examples is China Synthetic Rubber Company (CSRC). Since 1993, CSRC has engaged in developing an orphan drug to cure Prompe's diseases, a genetic disease that paralyses new born babies. In order to develop the drug, CSRC participated equally with Synpac, an American company, to build up its own capability on clinical trial. The orphan drug was still in clinical trials in 2000. Another explanation accounting for the negative relationship between inter-firm co-operation and innovation is that the inter-firm links in the Taiwan biotechnology sector still mainly build for non-technological co-operation, such as product agency, contract manufacturing etc.

It is worth noting that the UK IC firms co-operation with firms, more specifically competitors and non-IC firms, could increase their innovation performance. Due to a lack of strong domestic IC industry clusters, the UK IC firms tend to ally with European IC and electronics firms (e.g., Philips, Thomson, Siemens) through the series of European framework programmes and with the world IT-related manufacturers in order to catch fast changing IC technology (Mytelka, 1991; Lawton, 1997). One best example is Advanced RISC Machine (ARM), the world leader in micro-processor design technology, who establishes more than 30 international license agreements with Texas Instrument, Motorola, Hitachi, etc.

5.2. *Firm-knowledge generating organization co-operation for innovation*

This study also reveals that the effective firm-knowledge generating organization (e.g., universities, governments, R&D institutions) links could act as a crucial source to increase the firm's innovative performance (such as the *firm-research* links in the four-sector regression and the Taiwan nation regressions and the *firm-government* links in four-sector regression, the UK nation regression, and the UK biotechnology sector).

Some literature indicates the importance of firm-university co-operation in enhancing the innovative activities of firms, especially in the biotechnology sector (Kenney 1986; Stankiewicz 1986). The study finds that firm-research co-operation partially significantly increases the probability of introducing technological innovation in the four-sector aggregation model and Taiwanese 2-sector aggregation model. Arora and Gambardella (1994) argue that the function of universities to the firm's innovative activities appear to be more important as evaluating sources of scientific information and capabilities, rather than as utilising sources of innovation.

Why are firms that participate in government projects more likely to innovate? In studying the dynamics between "star scientists" and the growth of US biotechnology firms, Zucker *et al.* (1998) claim that the biotechnology firms hiring star scientists can acquire high-quality information inputs more easily than those that do not, and in turn increase their potential to innovate and grow. Besides getting funds and building public relations, firms participating in government-initiated projects gain better access to star scientists and create a strategy posture to attract new talent to join the firms. Arguably, the Zucker *et al.* dynamics could form a virtuous cycle. Firms participate in government projects → able to access and hire star scientists → increase innovative performance → increase their chances to participate in next wave government projects. Once firms become more innovative and recognized by the general public, governments frequently invite these innovative firms as symbolic partners to jointly initiate government projects.

The study reveals that the inter-organizational links benefiting the firm's innovation performance tend to be nationally specific. There are two observations. Firstly, the inter-firm links and firm-government links play a key role in enhancing the innovative performance of the UK firms but do not apply to the Taiwanese firms. The DTI's (Department of Trade and Industry) support for SMEs (Small and Medium Sized Enterprises) through their schemes such as SPUR (Support for Products under Research) and SMART (Small Firms Merit for Research and Technology) plays a crucial role in promoting firm-government co-operation.

Second, the paper finds that *firm-research* links are the most crucial co-operation to improve firms' innovative performance in Taiwan but this does not apply to the UK firms. Backing up strong financial support from government agencies, non-profit R&D institutions (e.g., Development centre for Biotechnology; Biotechnology Engineering Centre, ITRI) and national government labs (e.g., Academic Sinica, National Health Research Institute) play a key role in developing pre-competitive technologies in Taiwan. Taiwanese firms actively transfer the R&D results from these R&D institutions. This result confirms the firm-R&D institution links in the Taiwanese firms remains one of the most important knowledge links in Taiwanese systems of innovation (Liu 1993; Hou and San 1993).

5.3. Size matters?

In the logistic regression model, the dependent variable, 'innovative performance' is dichotomous. It describes whether the firm introduces the technological innovation or not rather than the number of technological innovations introduced. In the settings, firm size (number of employees) is a partially significant variable in predicting the probability of introducing technological innovation in the four sector aggregation model, the UK biotechnology sector and the Taiwan IC sector.

However, some recent studies report that small firms are more innovative than big firms in term of innovations per thousand employees. Tether (1998) argues that the traditional 'object-based' innovation/size studies under-estimate the number of process innovations and neglect the economic/technological value of the innovations being introduced. If the value of innovation is considered rather than innovation count, he suggests that the value (in terms of sales) of innovation increases with the size of firm. The study has avoided the first bias of neglecting process innovation. But the value of innovation is not considered in the study.

Mytelka (1991) claims that the size of the individual firms is no longer a key determinant of introducing technological innovativeness. Rather, the scope and composition of the network within which the firm participates is a key factor. This makes the relation between size and innovation more equivocal. The unsolved debate is expected to continue while dynamic governance of innovation, and more precise measurement on value of innovation are taken on board.

5.4. System of innovation model vs. linear model

R&D intensity does not show a significant indicator to influence the firm's innovation performance in most models. This supports the view that R&D intensity has become a less powerful factor in predicting the firm's innovation performance than it was. The results also support the assertion that the 'linear model' of innovation (where an automatic transformation from research, to manufacturing, to marketing is assumed), is no longer of great value. All of this evidence supports the process whereby R&D expenditures are translated into innovation is neither automatic nor linear because the knowledge-intensive system of production is based upon a broad range of capabilities (Mytelka, 1991). The institutional environment, within which new knowledge is generated and diffused, is now more widely acknowledged to be a factor in shaping a firm's innovation (Edquist, 1997).

It is worth noting that the role of co-operation should be regarded as a supplement rather than a substitute to a firm's internal R&D. Firms need to develop internal capabilities in order to trade in co-operation and reap the benefits of co-operation.

6. Conclusions

The success of firms, regions, sectors and nations has become increasingly dependent on how effectively they generate and use knowledge in an increasingly interdependent economy. Based on the data of the IC sectors and biotechnology sectors across Taiwan and the UK during 1996–98, the relation between innovative activities and inter-organisational linkages is examined. The study reveals that some types of inter-organisational co-operation are positively associated with the firm's innovative performance. This preliminary result confirms the rising importance of systems of innovation that the innovation process or knowledge production is becoming both *collective* (Niosi, 1996) and *distributed* (Gibbons *et al.*, 1994; Coombs and Metcalfe, 1998) in nature. The firm's *networking capability* with suppliers, customers, and knowledge-creating organisations asserts a decisive influence on its innovativeness. The collective and distributed innovation process also indicates that a firm's innovative performance is not only shaped by internal R&D effort but also by external links with other firms and knowledge-creating organisations. Moreover, the paper argues that the latter becomes a more powerful factor in influencing a firm's innovativeness. Firms with a more active role in establishing inter-organisational linkages increase their chances to innovate.

However, co-operation is a long term and trust-building, trust-based process between partners. In particular, co-operation with universities or other knowledge-creating organisations is not an easy task for firms, because such co-operations usually involve complex institutional and regulatory arrangements and sometimes, conflicting interests among partners. Firms urgently need to learn how to manage inter-organisational co-operation and this includes learning about partner selection, mutual trust building and the materialisation of resulting benefits. Policy for promoting firms' innovation network/community should be encouraged as a response to the increasingly systemic nature of innovative activities.

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Appendix

Interpretation of results

To interpret the results of the model, the study assumes Y = Logit (p)

$$\begin{aligned} Y &= \text{Logit (p)} \\ &= \log\,[\text{odds of event occurring}] \\ &= B_0 + B_1{}^*X_1 + B_2{}^*X_2 \ldots + B_n^*X_n \ldots \quad (2) \end{aligned}$$

Where:

Odds of event occurring $= p/(1-p)$;
P is the probability of event occurring and $(1-p)$ is the probability of event not occurring.

We can calculate the probability of an event occurring thus:

$$\text{P (event occurring)} = e^Y/(1+e^Y)\ldots \quad (3)$$

Regarding exp (B), the odds $[p/(1-p)]$ will change exp (B_n) times of its previous value by increasing one unit of the variable X_n. Finally, some examples will illustrate the possibilities of how a firm is likely to introduce technological innovation by using equation (2).