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Policy tools on the formation of new biotechnology firms in Taiwan

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Abstract

This research explores the contribution of policy tool toward the formation of Taiwanese biotechnology firms. The effect of technological policy for the formation of new biotechnology firms (NBFs) is complicated by the fact that biotechnology is new, and its development raises issues where there is a great deal of uncertainty. This research involved the evaluation of policy tools on the formation of NBFs and was based on a combination of fuzzy multiple criteria decision-making method (MCDM) and interviews with key actors in the field. The focus of this paper is how the users, biofirms, and venture capitalists perceive the contribution of policy tools toward the formation of NBFs. The evaluating hierarchy toward the formation of NBFs shows that two user groups perceive differently. Venture capitalists emphasize the importance of factors relating to technology and human resources, while biofirm groups emphasize those relating to market. The results of the evaluation reveal that: First, policy tools relating to technology and human capital are currently the main focus in Taiwan, a focus consistent with the perception of venture capitalists. However, from the perspective of biofirms, there are mismatches. Second, policy tools contribute to the formation of NBFs in different ways. Some contribute more widely across the criteria, while some are more specific. Third, the ranking of eight policy tools indicates that the role of public research institutes in economic development has become more sophisticated. Not only are they the source of initial capabilities of emerging firms, they are also important actors in industrial innovation, especially for a knowledge-intensive, industry-like biotechnology.

Keywords: Policy tools; Biotechnology; Multiple criteria decision making; New biotechnology firms

1. Introduction

Biotechnology is recognized as one of the strategic technologies of the 21st century. Many countries develop their technology policies to enable them to acquire competencies in this field. Although technological development is considered a location-specific phenomenon, the experience of advanced economies enables us to identify a number of factors critical for the establishment of biotechnology industry. From a review of literature three major issues appear to be significant to the development of biotechnology industry. First, since biotechnology industry is a science-based industry, the creation of high-level scientific capabilities is crucial. Second, the formation of new biotechnology firms is a dominant phenomenon. Finally, to apply biotechnology to industry requires competence in existing biology-related process technologies and complementary assets, such as marketing. For developing countries with a weak science base and limited complementary assets, the formation of new biotechnology firms is likely to be a strategic focus and a good indicator of biotechnology development at an early stage.

Taiwan has identified biotechnology as one of its strategic foci for technology development since the early 1980s. Although the Taiwanese Government has put in a great deal of effort, the progress of biotechnology industry has not been as good as predicted. The total industrial output of Taiwan's biotechnology industry was less than 600 million US dollars in 2000, and most of the output was traditional bio-product related, rather than modern biotechnology products. On the other hand, the fast growth of biotechnology firms in the past 5 years is possibly a good indicator for future success. Nearly 100 new biotechnology firms have been established between 1997 and 2001. The question is what kinds of policies have Taiwan's Government implemented, and how effective are they?

Creating new firms is considered an important element in economic health, and many governments have established policies to encourage it (Abernathy and Utterback, 1978; Rothwell, 1984). The effectiveness of each policy tool toward the formation of NBFs is, however, difficult to

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evaluate for several reasons: First, the formation of NBFs can be affected by a number of factors other than policy. They include: science base, entrepreneurial climate, venture capital market, IPO capital gain, financial motives, source of intellectual capital, links between public and private research, demands for biotechnology product, public acceptability, and large established enterprises. Second, the effects of each policy on new firm creation are too complicated and may vary among different industries and countries. Third, the new biotechnology firm is a new phenomenon in the development of biotechnology. Neither the previous experiences of advanced economies nor theory can be directly applied in evaluating the policy tools. Finally, the effectiveness of a policy tool is also influenced by the capability of users and its implementation rather than the policy tool itself.

The authors do not intend to answer questions about the effectiveness of each policy tool definitively; rather, the focus of this paper is to explore how the users, biofirms, and venture capitalists perceive the contribution of each policy tool toward the formation of NBFs. The research involved the evaluation of policy tools on the formation of NBFs and was based on a combination of fuzzy multiple criteria decision method (MCDM) and interviews with key actors in the field.

This paper is organized as follows: Section 1 describes the problems and purposes of the research. Section 2 discusses the background for industrial innovation and biotechnology and the current situation of the developments of biotechnology in Taiwan, as well as a number of policy tools. Section 3 proposes the fuzzy multi-criteria approach as the research methodology. Section 4 presents a hierarchy model for 'the formation of new biotechnology firms' and discusses the weights of criteria. Section 5 evaluates eight policy tools according to the criteria. Finally, Section 6 presents the conclusions.

2. Industrial innovation of biotechnology

Modern biotechnology began in 1973 when Herbert Boyer and Stanley Cohen discovered the technique for recombinant DNA, which became the basis of genetic engineering. The commercialization of biotechnology, however, owes its development to the cooperation of a venture capitalist and a scientist. Swanson and Boyer founded Genetech in 1973. The successful outcome of this company showed the commercial potential of recombinant DNA techniques. Afterwards, many new biotechnology firms were born and played a key role in the development of biotechnology industry in the USA and other countries (Senker, 1996).

Three characteristics are particularly noteworthy in distinguishing the development of biotechnology from other sectors' development (Swann and Prevezer, 1996; Gersony, 1996). First, biotechnology is not an industry defined by products or services, such as textiles or telecommunication. It applies molecular biology to produce and transform materials and is also a means of production. Consequently, biotechnology has commercial application for products and processes across a wide variety of industrial sectors, including pharmaceuticals, food processing, waste water treatment, etc. Second, biotechnology depends highly on basic research in molecular biology. A close connection thus clearly exists between basic scientific research and commercial biotechnology. Third, there is a substantial uncertainty and controversy surround the commercialization of genetic engineering research. These characteristics are important in understanding how different national institutional environments have shaped different approaches to biotechnology innovation.

2.1. Government interventions for industrial innovation

Government interventions are theoretically justifiable when markets fail in technological and industrial development. Justification for government intervention derives from certain principles: First, technological progress may not proceed in the desired direction without influence by government. Second, the difficulty in 'appropriating' a return from R&D reduces the incentive to invest in 'knowledge production' by the private sectors. Third, the pressure of global competition forces developing countries to make interventions to nurture their infant industries that are unlikely to evolve spontaneously.

The manner in which government policy is made operational is through policy tools. A policy tool can be defined as a set of means used when putting a given policy into practice. Policy tools are generally classified into three broad categories: inputs-supply side, demand side, and environment side (Rothwell et al., 1981). A government seeking to influence the supply side of the industrial innovation process can improve the education system, the scientific and technical institutions, and information networks, or it can directly participate as a public enterprise. A government wishing to improve the demand side of the innovation process may directly purchase new products, contract research projects, or indirectly regulate tariffs. Finally, a government can alter the overall environment through taxation, regulations, policies, and financial measures.

Although there remains substantial controversy on the role of governments and free market, it is now accepted that most east Asian governments have intervened widely and in many different ways. Taiwan is no different. Technology policy has played an active role in its industrial development for the past half century. Policy tools, such as the establishment of science-based parks, government-funding for R&D projects, tax exemption programs for high-tech industries, and direct investments in several spin-off firms have demonstrated their success in fostering Taiwan's IC industry.

When a government designs and implements its technology policy, failure is always a possibility. To reduce the likelihood of failure, Wegloop (1995) argued that policy should be developed in a bottom-up manner. In this research we took this view and emphasize that appraisal of technology policy from a user's perspective is valuable for policy-making. Lall and Teubal (1998) argue that well-designed interventions will always promote faster development as long as there are market failures and strategic needs.

2.2. Policy tools for new firm formation in biotechnology

The formation of new biotechnology firms is recognized as a dominant phenomenon in the development of biotechnology. Much of the literature on NBFs has focused on those established in the US, which has a strong philosophy against direct intervention. However, various policy tools were taken to favor the formation of new firms in many countries. Storey and Tether (1998) reviewed the public policy measures implemented in EU countries to support new technology-based firms (NTBFs) during the 1980s and 1990s. They identified five policy areas, including: science parks, the supply of PhDs in science and technology, the relationships between NTBFs and universities/research institutions, direct financial support, and the impact of technological advisory services.

Walsh et al. (1995) compared the pattern of emergence, survival, and growth of biotechnology firms in France, Britain, and Canada with the United States. Walsh et al. reported that a comparable pattern of small firm commercialization of biotechnology was observed in the three countries studied; although, the Canadian, French, and British firms appeared 1 to 4 years later than the US firms and are still weaker. They also analyzed the differences in the financial institutions and instruments of public policy in these four countries. Several policy tools were implemented to favor the formation of NBFs by removing the institutional obstacles to entrepreneurship, enhancing the links between public and private sector research, providing government grants, encouraging cooperative networks, and offering tax deduction programs.

Senker (1996) compared the different patterns of biotechnology development between the US and the UK. The author reported that the formation of NBFs in the UK was slow until the government intervened. Momma and Sharp (1999) discussed the development of NBFs in Germany and concluded: First, Germany now has a substantial number of NBFs, and the numbers are steadily increasing. Second, German NBFs are similar to their counterparts in other countries in several aspects, such as a high research density, the geographical proximity to centers of scientific excellence, and a number of collaborations with research institutions. Third, the number of these companies is increasing because of substantial adaptation of the institutional framework. This research implied that active government intervention might be required to create the conditions for new biotechnology firms.

Fontes and Novais (1998) examined the evolution of the biotechnology industry in Portugal. They argue that the formation of new firms require the emergence of technological opportunities, talented entrepreneurs, demand for biotechnology products, and many other factors. It appeared that Portugal's government policies were relatively successful in strengthening the competency of public research, but not in promoting the transfer of the competency to industry.

2.3. New biotechnology firms in Taiwan

Taiwan identified biotechnology as one of eight key areas for technology development in early 1980s. For the purpose of technology development and technology transfer, the Development Center of Biotechnology was established in 1984 and several research organizations that included Biomedical Engineering Center and National Gene Research Center were established in the previous decade. To further strengthen the development of biotechnology industry, a program that increased the government's R&D expenditure and improved the infrastructure was launched in 1995. In addition, a national level conference for biotechnology named ‘Strategic Review Board, SRB’ has been held annually since 1997 to which experts from academia and industries are invited to discuss the strategy of biotechnology development and review its progress. Nurturing biotechnology firms is one of the main themes of the SRB meeting (S&T Advisory Board, 2000).

From 1997 to October 2001, 99 biotechnology firms were established in Taiwan, representing nearly half of the total number of Taiwanese biotechnology companies. According to the reports from the Ministry of Economic Affairs (ITIS, MOEA, 2002), the top five categories of these firms are biotech medicine (27.4%), reagent (13.1%), agricultural biotechnology (12.1%), health food and Chinese herbs (10.1%), and biochips (9.0%). Owing to the great success of the first IPO (initial public offer) of Apex Biotech Corporation in the year 2000, over 30 biotechnology firms are now waiting to go public. However, nearly 70% of these firms are OEM-based manufacturing companies. Many of them are subsidiary units, branch offices, or joint ventures of foreign companies including UBI, PBM, IVAX, ATI, and Celera. Local scientists have only founded a small proportion of Taiwan's new start-ups.

3. Methodology

This paper presents a method that includes: (1) using an analytical hierarchy process (AHP) method to construct an evaluating hierarchy from the users' perspective; (2) a group-decision method used by experts and based on predetermined criteria/factors; and (3) the fuzzy approach in scoring the subjective judgements of the experts.

3.1. Evaluating the weight for the hierarchy system

The AHP weighting (Saaty, 1980) is determined by pair-wise comparisons on the evaluating criteria. Saaty used the principal eigenvector of the pair-wise comparison matrix derived from the scaling ratios to find the relative weight importance among the criteria of the hierarchy system. Suppose there is a set of n criteria in pairs according to their relative weight scaling. Denote the criteria by $c_1, c_2, ..., c_n$ and their weights by w_1, w_2,...,w_n. If $\mathbf{w} = (w_1, w_2, ...w_n)^t$ is given, a matrix $\boldsymbol{A}$ of the following equation can represent the pair-wise comparisons,

$$(\boldsymbol{A} - \lambda_{\max}\boldsymbol{I})\boldsymbol{w} = 0. \quad (1)$$

Then we can find the eigenvector $\boldsymbol{w}$ with its $\lambda_{\max}$ which satisfies $\boldsymbol{Aw} = \lambda_{\max}\boldsymbol{w}$. Since the relative importance comparisons are derived from intuitive judgments, a certain degree of inconsistency exists. Saaty (1980) used the consistency index (CI) as an indicator of 'closeness to consistency', $\mathrm{CI} = (\lambda_{\max} - n)/(n - 1)$. In general, the value of $\lambda_{\max}$ can be accepted if CI is not greater than 0.1.

3.2. The performance value of the policy tools

Since Zadeh (1965) first introduced fuzzy set theory and subsequently the fuzzy decision-making method (Bellman and Zadeh, 1970) in fuzzy environments, many other studies have dealt with uncertain fuzzy problems by applying fuzzy set theory. Fuzzy approach is thus suitable to obtain the performance value because the performance scores for each policy tool are usually based on subjective judgments of evaluators. The application of fuzzy theory can be described as follows:

a. Fuzzy numbers: According to the definition of Dubois and Prades (1978), the fuzzy number $\tilde{A}$ is a fuzzy set, and its membership function is $\mu_{\tilde{A}}(x) : R \rightarrow [0, 1]$, where x represents the policy tools. It is common to use triangular fuzzy numbers (TFNs) $\mu_{\tilde{A}}(x) = (L, M, U)$, as shown in Eq. (2):

$$\mu_{\tilde{A}}(x) = \begin{cases} (x - L)/(M - L), L \leq x \leq M \\ (U - x)/(U - M), M \leq x \leq U \\ 0, \text{otherwise} \end{cases} \quad (2)$$

b. Linguistic variable: A linguistic variable is a variable whose values are words or sentences in natural or artificial language. For example, the expressions of criteria such as 'favorable environment' and 'opportunity for going public' represent linguistic variables in the context in these problems. Linguistic variables may take on effect values such as 'very high', 'high' 'medium', 'low', 'very low'. Evaluators assign subjective weights to the linguistic variables.

3.3. Evaluating the policy tools

This paper applies fuzzy multiple criteria decision-making method (Fuzzy MCDM) to evaluate the policy tools and rank them. The method and procedure of Fuzzy MCDM method are as follows:

a. Measuring criteria: Let $\tilde{E}_{ij}^k$ be the fuzzy performance value of k^{th} evaluator toward policy tool i under criterion j. and let the performance of the criteria be indicated by a set S,

$$\tilde{E}_{ij}^k = (LE_{ij}^k, ME_{ij}^k, UE_{ij}^k), j \in S$$

Since the perception of each evaluator varies according to the evaluator's knowledge and experience, the definitions of the linguistic variables vary as well. Thus, this study uses the notion of average value so as to integrate the fuzzy judgment values of m evaluators, that is,

$$\tilde{E}_{ij} = (1/m)\otimes(\tilde{E}_{ij}^1 \oplus \tilde{E}_{ij}^2 \oplus ... \oplus \tilde{E}_{ij}^m)$$

where the sign $\otimes$ denotes fuzzy multiplication, the sign $\oplus$ denotes fuzzy addition, $\tilde{E}_{ij}$ is the average fuzzy number of the judgment of m evaluators, and a triangular fuzzy number is shown as:

$$\tilde{E}_{ij} = (LE_{ij}, ME_{ij}, UE_{ij})$$

The proceeding end-point values $LE_{ij} = (1/m)(\sum_{k=1}^m LE_{ij}^k), ME_{ij} = (1/m)(\sum_{k=1}^m ME_{ij}^k)$ and $UE_{ij} = (1/m)(\sum_{k1}^m UE_{ij}^k)$.

b. Fuzzy synthetic decision: The weights of the criteria and the fuzzy performance values must be integrated by the operation of fuzzy numbers. According to the weights w_j derived by AHP method, we get a weight vector w. Then the fuzzy performance matrix $\tilde{E}$ of each of the policy tool can be obtained from the fuzzy performance value of each policy tool under n criteria, that is,

$$w(w_1, w_2, ..., w_n)^t$$
$$\tilde{E}(\tilde{E}_{ij})$$
$$\tilde{R}\tilde{E} * w$$

The sign '*' indicates the operation of the fuzzy numbers, including fuzzy addition and multiplication. Because the operation of fuzzy multiplication is relatively complex, it is usually denoted by an approximate multiplied result $\tilde{R}$ which is a fuzzy number $(\tilde{R}\tilde{R}_1, ..., \tilde{R}_i, ..., \tilde{R}_I)$. It can be expressed as follows:

$$R_i(LR_i, MR_i, UR_i), \forall i$$

$$LR_i \sum_{j1}^{n} LE_{ij} w_j$$

$$MR_i \sum_{j1}^{n} ME_{ij} w_j$$

$$UR_i \sum_{j1}^{n} UE_{ij} w_j$$

c. Comparison of the policy tools: The result of the fuzzy synthetic decision reached by each policy tool is a fuzzy number. Therefore, it is necessary to transform a fuzzy number into a non-fuzzy number in order to compare them. In many research projects the procedure for defuzzification is to locate the best non-fuzzy performance (BNP) value. Methods of such defuzzified ranking include the mean of maximal (MOM), center of area (COA), and -Cut (Zhao and Goving, 1991; Teng and Tzeng, 1996). Utilizing the COA method to determine the BNP is simple and practical. The BNP value of the fuzzy number can be calculated as follows:

$$BNP_i LR_i [(UR_i LR_i)(MR_i LR_i)]/3, \forall i.$$

Then the policy tools can be compared according to the BNP value.

4. Evaluating model for the formation of NBFs

We first proposed an evaluating hierarchy and then revised it according to the opinion of expert groups. More than 40 criteria were initially proposed based on literature review (Walsh et al., 1995; Senker, 1996; Gersony, 1996; Berry, 1996; Bartholomew, 1997; Oliver and Liebeskind, 1997/1998; Fontes and Novais, 1998; Storey and Tether, 1998; Janszen and Degenaars, 1998; Momma and Sharp, 1999; Hall and Bagchi-Sen, 2002)). A group of 60 experts from biofirms and venture capitalists were asked to compare the criteria pair-wisely according to their relative importance to the formation of NBFs in Taiwan. The hierarchy model for evaluating the formation of NBFs is shown as Fig. 1.

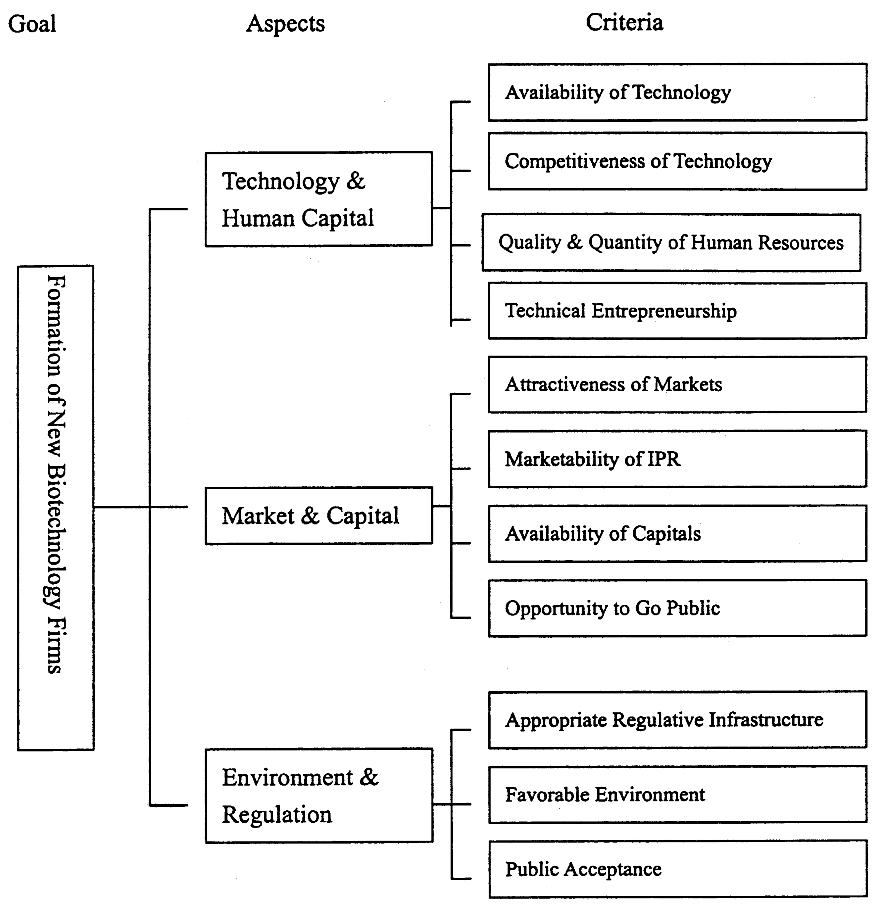

Fig. 1. Evaluating hierarchy for the formation of new biotechnology firms.

Table 1
The preference structure of the evaluation aspects toward the formation of NBFs

Aspect	Biofirm group	VC group
Technology and human capital	0.323 (0.129, 0.401)	0.442 (0.161, 0.365)
Market and capital	0.353 (0.194, 0.549)	0.266 (0.085, 0.320)
Environment and regulation	0.324 (0.175, 0.541)	0.292 (0.114, 0.392)

Figures in parentheses show the standard deviation and coefficient of variation, respectively.

4.1. Criteria toward each aspect of the formation of NBFs

1. Technology and human resources aspect: The supply of human resources and technology related to the formation of biotechnology firms including:
   a. Availability of technology: The availability of technology for new biotechnology firms;
   b. Competitiveness of technology: The competitiveness of the technology compared with existing technology, including production cost, performance of products, and position of intellectual property rights;
   c. Quality and quantity of human resources: The supply of technical personnel and the quality of the workforce;
   d. Technical entrepreneurship: The tendency of the technical experts to be entrepreneurs.
2. Markets and capital aspect: The potential markets of biotechnology applications and the availability of capital for the formations of NBFs, including:
   e. Attractiveness of markets: The market size, growth and profitability of the applications;
   f. Marketability of IPR: The market value before commercialization and the marketability of intellectual properties of biotechnology;
   g. Availability of capital: The availability and the total cost of capital raising, including venture capitals market and stock markets;
   h. Opportunities to go public: The opportunities for biotechnology firms to go public and the value creation or capital gains when its IPO (initial public offer) is made.
3. Environment and regulations:
   i. Appropriate regulative infrastructure: Good quality of regulatory infrastructure, such as an efficient pharmaceutical product registration process, a clinical trial system, etc.;
   j. Favorable environment: A proper environment for biotechnology development and new setups;
   k. Public acceptance of biotechnology: Public concerns about biotechnology products, such as gene-modified foods and the controversy on human-cloning techniques, including the attitude of religious societies.

4.2. Weights of criteria for evaluating the formation of NBFs

The results of evaluating criteria and their weights are summarized in Tables 1 and 2. Venture capitalists weighed the aspect of ‘Technology and human capital’(0.442) higher than the other two aspects (0.292 and 0.266), while the biofirm group weighed the three aspects as nearly equally important. The results given in Table 1 and Table 2 suggest that:

1. The preference structures of the two groups are different. Venture capitalists rated ‘Competitiveness of technology’(0.155) as the most important criterion contributing to the formation of new biotechnology firms, followed by

Table 2
The preference structure of each group toward criteria

Criteria	Biofirms group	VC group
Availability of technology	0.080 (0.068, 0.858)	0.038 (0.012, 0.324)
Competitiveness of technology	0.094 (0.047, 0.502)	0.155 (0.045, 0.292)
Quality and quantity of human resources	0.079 (0.048, 0.604)	0.114 (0.072, 0.630)
Technical entrepreneurship	0.069 (0.073, 1.056)	0.134 (0.056, 0.419)
Attractiveness of market	0.138 (0.108, 0.641)	0.066 (0.027, 0.413)
Marketability of IPR	0.102 (0.047, 0.460)	0.056 (0.031, 0.561)
Availability of capital	0.045 (0.023, 0.513)	0.059 (0.053, 0.884)
Opportunity to go public	0.067 (0.067, 0.998)	0.083 (0.052, 0.616)
Appropriate regulative infrastructure	0.118 (0.131, 1.110)	0.122 (0.097, 0.791)
Favorable environment	0.084 (0.075, 0.891)	0.103 (0.048, 0.462)
Public acceptance	0.121 (0.065, 0.538)	0.065 (0.072, 1.104)

Figures in parentheses show the standard deviation and coefficient of variation, respectively.

'Entrepreneurship of technical personnel'(0.134), 'Appropriate regulative infrastructure'(0.122), 'Quality and quantity of human resources'(0.114), and 'Favorable environment'(0.103). Experts from biofirms rated 'Attractiveness of market'(0.138) as most important, followed by 'Public acceptance'(0.121), 'Appropriate regulative infrastructure'(0.118), 'Marketability of IPR'(0.102), and 'Competitiveness of technology '(0.094). The figure in parenthesis represents the weight of that criterion. The results imply that the biofirm group emphasizes those criteria relating to market, whereas the venture capitalist group is concerned more about technology and human resources. Both groups recognize the importance of the regulative infrastructure and a favorable environment. One explanation could be linked to the role of each group and their expectations for that role. Venture capitalists always seek talented people and brilliant ideas. They recognized the importance of the quality of the technical team and the technology itself for the success of new setups. Furthermore, venture capitalists expect return mainly from capital gains when going public instead of profiting from product sales. Biotechnology firms, on the other hand, tend to develop technology by themselves and look for commercial success of products.

2. It is also noteworthy that 'Marketability of IPR' and 'Public acceptance' draw more attention from the biofirm group than from venture capitalists. The biofirm group recognizes public concerns about biotechnology products such as gene-modified foods and human-cloning techniques, and mentions them as major barriers to the development of biotechnology, while venture capitalists do not. Some of the venture capitalists mentioned that public concern is not a big issue in Taiwan. Moreover, they think that such concerns revolve around only a small part of biotechnology products, and that there is still much room for developing biotechnology. This attitude may reflect the risk-taking characteristic of venture capitalists. Similar to their counterparts in advanced economies, small biotechnology firms in Taiwan tend to develop their technology and look for opportunities to go public or to be acquired. The intellectual property rights of their technology are usually the most, and probably the only, valuable asset for going public or for being acquired, which probably explains why the biofirm group emphasizes the criterion of the marketability of IPR.
3. Both groups weighted the criteria of 'Availability of technology' and 'Availability of capital' lower. Interview results revealed that raising capital is usually not too difficult because the venture capital market in Taiwan is very active. They also thought that the technology mainly rested with the scientist and thus emphasized the importance of human resources instead of the availability of technology.

4.3. Policy tools for biotechnology industry in Taiwan

We conducted a survey of the policy tools that favor the development of biotechnology in Taiwan and grouped them into 17 categories (see Appendix 1). Although none of the Taiwanese government's programs have been designed specifically to promote the formation of new biotechnology firms, the authors asked the users group to rate each policy tool on a one-to-five scale according to its relevance to the formation of NBFs. Among the top 10 policy tools rated by two groups, eight policy tools are same. They are 'Applied research programs', 'Assisting programs for new product development', 'Research institutes', 'Overseas experts recruiting program', 'Training programs', 'Clinical trial system for new drug development', 'Financial incentives', and 'Incubating programs'. The authors noted that the rating of the biofirm group, which falls in the range from 3.5 to 4.6, is higher than that of the venture capitalist group (2.71–4.0), which implies that venture capitalists perceive the policy tool to be less important than biofirms do.

5. Evaluation of policy tools

The evaluation of policy tools according to each predetermined criterion was conducted by a different group of experts for two reasons: First, venture capitalists and experts of biofirms are not necessarily experts of technological policy. Their insufficient knowledge of policies could lead to an unreliable evaluation result. Second, biased judgment may exist because the evaluators, who are the users of policy tools, tend to judge based on their own interests. For example, an expert from a biofirm usually prefers policies such as 'Tax exemption', 'Market protection', and 'Subsidized measures'. We thus organized a separate group for evaluating policy tools. Ten evaluators who have deep understanding of technology policy, but are not necessarily familiar with biotechnology were invited to evaluate the contribution of each policy tool according to the predetermined criteria. Each evaluator was asked to express his/her perception, which was based upon a set of five levels of linguistic variables in a triangular fuzzy number in order to cope with the ambiguities of judgments. The performance scores of the second group toward each criterion are shown before taking the weighting factor into account in Table 3. If we use the BNP value as an indicator of the degree of contribution, we divide the range of BNP value equally into five levels and name them 'VH, very high', 'H, high', 'M, medium', 'L, low', and 'VL, very low'. The performance score, which is labeled 'VH' and 'H', indicates that the policy tool contributes to the criterion in a relatively significant way. We noted that:

1. The performance scores of policy tools distribute unevenly among criteria. These eight policy tools

Table 3
The performance scores of policy tools toward each criterion

Policy tool Criteria	Applied research programs	Assisting programs for NPD	Training programs	Overseas experts recruiting	Research institutes	Clinical trial system for new drugs	Incubating programs	Financial incentives
Availability of technology	76.5 (67.5,76.3,85.6) H	71.9 (61.9,71.9,81.9) H	46.6 (34.4,46.3,58.8)	61.9 (51.3,61.9,72.5)	75.4 (65.6,75.0,85.6) H	55.2 (43.1,55.0,67.5)	64.8 (54.4,64.4,75.6)	76.5 (67.5,76.3,85.6) H
Competitiveness of technology	80.2 (70.6,80.0,90.0) VH	79.6 (70.6,79.4,88.8) VH	72.1 (61.9,71.9,82.5) H	80.0 (70.6,80.0,89.4) VH	84.6 (75.6,84.4,93.8) VH	73.1 (63.1,73.1,83.1) H	69.4 (60.0,69.4,78.8)	65.0 (55.0,65.0,75.0)
Quality and quantity of human resources	76.8 (67.5,76.9,86.3) H	71.9 (61.9,71.9,81.9) H	80.8 (72.5,80.6,89.4) VH	87.7 (80.0,87.5,95.6) VH	83.9 (75.6,83.8,92.5) VH	61.5 (51.9,61.3,71.3)	73.9 (64.4,73.8,83.8) H	62.5 (53.1,62.5,71.9)
Technical entrepreneurship	63.3 (53.8,63.1,73.1)	77.1 (66.9,76.9,87.5) H	59.4 (47.5,59.4,71.3)	78.1 (68.1,78.1,88.1) H	73.1 (63.1,73.1,83.1) H	69.6 (60.6,69.4,78.8)	85.2 (76.9,85.0,93.8) VH	78.3 (70.0,78.1,86.9) H
Attractiveness of markets	60.6 (50.0,60.6,71.3)	74.4 (65.6,74.4,83.2) H	42.1 (30.6,41.9,53.8)	60.0 (49.4,60.0,70.6)	68.3 (58.1,68.1,78.8)	74.6 (65.6,74.4,83.8) H	63.3 (51.9,63.1,75.0)	62.1 (51.3,61.9,73.1)
Marketability of IPR	70.2 (59.4,70.0,81.3) H	72.9 (63.1,72.5,83.1) H	51.3 (38.1,51.3,64.4)	52.3 (41.3,51.9,63.8)	72.3 (61.9,71.9,83.1) H	63.1 (51.9,63.1,74.4)	69.8 (59.4,69.4,80.6)	63.5 (51.9,63.1,75.6)
Availability of capital	32.3 (20.0,31.8,45.0)	51.9 (42.5,51.9,61.3)	38.3 (25.6,38.1,51.3)	44.6 (31.9,44.4,57.5)	47.7 (35.6,47.5,60.0)	47.1 (34.3,46.9,60.0)	60.8 (49.4,60.6,75.2)	83.9 (75.8,83.8,93.1) VH
Opportunity to go public	58.3 (46.9,58.8,71.3)	75.0 (66.3,75.0,83.8) H	45.2 (34.4,45.0,56.3)	54.6 (44.4,54.4,65.0)	64.8 (53.1,64.4,76.9)	73.3 (63.1,73.1,83.8) H	72.1 (61.8,72.0,83.1) H	79.0 (70.0,78.8,88.1) H
Appropriate regulative infrastructure	46.0 (35.0,45.6,57.5)	58.9 (46.9,58.8,71.3)	46.0 (35.0,45.6,57.5)	48.5 (36.3,48.1,61.3)	57.1 (45.6,56.9,68.8)	76.7 (66.9,76.3,86.9) H	52.9 (41.3,52.5,65.0)	59.6 (48.1,59.4,71.3)
Favorable environments	59.6 (48.1,59.3,71.3)	66.5 (55.6,66.3,77.5)	57.1 (45.6,56.9,68.8)	62.9 (52.5,62.5,73.8)	77.5 (68.1,77.5,86.9) H	78.3 (68.1,78.1,88.9) H	71.4 (60.6,71.3,82.5)	81.3 (71.9,81.3,90.6) VH
Public acceptance	50.2 (38.1,50.0,62.5)	57.5 (46.9,58.8,71.3)	57.1 (46.3,56.9,68.1)	57.5 (46.3,57.5,68.8)	60.8 (49.4,60.6,72.5)	68.8 (58.8,68.8,78.8)	56.5 (45.6,56.3,67.5)	60.6 (49.4,60.6,71.9)

Figures in parentheses represent the triangular fuzzy numbers.

contributed to the 'Technology and human capitals' related criteria more significantly than to the 'Market and capital' and 'Environment and regulation' related criteria.

2. Various policy tools contribute to different degrees toward each criterion. If we map the weighting structure by the distribution of performance scores, we find that there are mismatches of policy from the perspective of biofirms, while there is a better fit from the perspective of venture capitalists. For example, several policy tools contribute significantly to the criteria that were weighted relatively high by venture capitalists. Those criteria include 'Competitiveness of technology', 'Entrepreneurship of technical personnel', and 'Quality and quantity of human resources'. Meanwhile, these eight policy tools contribute less significantly to lower-weighted criteria, such as 'Public acceptance' and 'Availability of capital'. In contrast, few policy tools significantly contribute to the criteria that were rated high by experts of biofirms. These criteria include 'Attractiveness of market' and 'Public acceptance'.
3. Policy tools contribute to the formation of NBFs in different ways. Several policy tools contribute to a large number of criteria, whereas some are more specific. For example, the policy tool of research institutes significantly contributes to increasing the availability and competitiveness of technology, enhancing the quality and quantity of human resources, encouraging the entrepreneurial climate, creating a favorable environment, and increasing IPR's marketability. But the policy tool for training programs contributes in a more specific way by improving the quality and quantity of human resources, as well as technological competitiveness. We cannot conclude that policy tools with wider impact are superior to those with specific impact, but this information is useful for policy tool design.

Table 4
Ranks of each policy tool—contribution perceived by Bio-firm group

	Technology and human capital	Market and capital	Environment and regulation	BNP (ranks)
Applied research programs	24.10	20.89	16.53	61.52 (7)
Assisting programs for NPD	24.23	25.06	19.51	68.80 (2)
Training programs	20.98	15.79	17.15	53.92 (8)
Overseas experts recruiting	24.78	19.28	17.99	62.05 (6)
Public research institutes	25.67	23.29	20.62	69.58 (1)
Clinical trial system	20.95	23.76	23.97	68.68 (3)
Incubating programs	23.43	23.43	19.09	65.95 (5)
Financial incentives	22.57	24.12	21.21	68.89 (4)

5.1. Contribution of policy tool perceived by the users' group

Overall performance scores according to the evaluating hierarchy and their criteria/weights are shown as Tables 4 and 5.

It is noteworthy that the ranking orders of both groups are nearly the same regardless of their different weighting structures. 'Research institute' and 'Assisting program for NPD' are the two policy tools that contribute toward the formation of dedicated biotechnology firms most significantly, followed by 'Clinical trial system', 'Financial incentives', and 'Incubating program'. 'Overseas experts recruiting programs' and 'Applied research programs' are ranked sixth and seventh. 'Training programs' is ranked last.

Further analysis on the ranks in each aspect reveals that:

1. Research institute and overseas experts recruiting program are the two policy tools that make the highest contribution to the formation of NBFs in terms of technology and human capital. Research institute is by nature a technology producer and is also a human resource provider if the mobility of technical experts is high. According to statistics of the Industrial Technology Research Institute (ITRI), a nonprofit research organization funded by the Taiwanese government, nearly 14 000 employees have left ITRI in the past 20 years. Sixty percent of them went to work for high-tech firms. The success of business in the Hsin-Chu Science Base Industrial Park encouraged the movement of researchers to industry. Overseas, Chinese have also been recognized as a major source of new technology and expertise in Taiwan. In the past two decades, many scientists and engineers who work for leading high-tech enterprises, mainly in the United States, have come back to Taiwan to initiate their own business or join local firms. This kind of human capital flow has been vital to the success of the development of semiconductor and computer industries in Taiwan.
2. The policy tools of assisting programs for new product development and financial incentives contribute most significantly in terms of market and capital. Financial incentives contribute by increasing opportunities for going public and the availability of capital. Meanwhile, assisting programs contribute to the 'Market and capital' aspect by enhancing market attractiveness and marketability of intellectual property rights as shown in Table 3.
3. Clinical trial system is ranked as the highest policy tool in contributing to the aspect of 'Environment and regulation', followed by the policy tool of financial incentive. The establishment of a clinical trial system is, no doubt, good for the infrastructure and environment. Financial incentives contribute mainly to creating a favorable environment. It is interesting to note that the policy tool of research institute is also ranked high in this aspect. It is probably related to the active role of public research institute in advising and lobbying the government on matters of regulation and policy.

Table 5
Ranks of each policy tool—contribution perceived by venture capitalists

	Technology and human capital	Market and capital	Environment and regulation	BNP (ranks)
Applied research programs	32.58	14.69	15.01	62.28(7)
Assisting programs for NPD	33.59	18.56	17.78	69.93(2)
Training programs	30.11	11.66	15.21	56.98(8)
Overseas experts recruiting	34.07	14.05	16.14	64.26(6)
Public research institutes	35.35	16.75	18.90	71.00(1)
Clinical trial system	28.66	17.32	21.89	67.87(5)
Incubating programs	33.06	17.66	17.49	68.21(4)
Financial incentives	30.60	19.16	19.58	69.34(3)

5.2. Result of interviews

To verify the results of the research, the authors presented the findings to several key policy-makers and discussed the implications with them. First of all, policy-makers in Taiwan knew the importance and role of public research institutes quite well. They acknowledge that the research institutes in Taiwan contribute in many ways. These institutes provide talented entrepreneurs, a skilled workforce, as well as technologies for new firms. They also serve as a bridge among institutions and promote communication and interaction among the research community, financial institutions, and the emerging biotechnology industry. Some policy-makers mentioned that research institutes, especially large ones, as the most important 'technical arm' of the government. In fact, public research institutes implement a large portion of technological policy tools in Taiwan. Secondly, policy makers appreciate the value of the evaluating process, as well as the ranking results. Such a two-stage approach provides a less biased assessment from a user's perspective. The abundant information associated with the evaluation is recognized as very useful for policy-mix design as well.

Finally, policy-makers had few questions about the ranking of policy tools except for the contribution of 'Applied research programs', which is the main focus of government policy in terms of resource allocation. It is, contrary to what might be expected, much lower than the contribution of 'Assisting programs in NPD'. One explanation could be linked to the different purposes of the two kinds of programs. Applied research programs are 'technology-oriented' and focus on generic technology, while assisting programs for new product development are 'product-oriented' and aim at specific objectives. The former policy tool is thus perceived to contribute less directly to the formation of NBFs than the other.

6. Concluding discussion

The number of new biotechnology firms in Taiwan has grown rapidly since 1997. To study how users, biofirms, and venture capitalist perceive the contribution of policy tools toward the formation of NBFs, the authors applied a two-stage, fuzzy multiple criteria approach. The results of the evaluating hierarchy show that the two user groups perceive differently. Venture capitalists emphasized the importance of criteria/factors relating to technology and human resources, while biofirms group emphasized those relating to market. Such results can be explained by the differences in the roles of the two user groups and their expectations. Venture capitalists always seek talented people and brilliant ideas, and they recognize the importance of the quality of the technical team and technology itself to the success of new setups. Furthermore, venture capitalists expect return mainly from capital gains when going public, instead of making profits from product sales. Biotechnology firms, on the other hand, tend to develop technology by themselves and look for commercial success.

Further evaluation of policy tools revealed that: First, the performance scores of policy tools distribute unevenly among criteria, and various policy tools contribute to different degrees toward each criterion. The results suggest that technology and human resources are the main focus of Taiwanese government policy, and such a focus is consistent with the perception of venture capitalists. From the perspective of biofirms there are mismatches. Second, it is noteworthy that the overall ranking order of both groups is nearly the same, regardless of their different weighting structures. Policy tools of 'Research institutes' and 'Assisting program for new product development' are ranked as the highest two for their contribution to the formation of DBFs, followed by 'Clinical trial system for new drug development', 'Incubating programs', and 'Financial incentives'. 'Overseas experts recruiting programs' and 'Applied research programs' are perceived to contribute less significantly and are ranked as sixth and seventh tools. 'Training programs' is ranked last. This ranking order represents the relative effectiveness of each policy tool perceived by users. Third, our results suggest that the role of public research institute in economic development has become more sophisticated. Research institute, especially large public research institutes, plays an important role not only in developing and disseminating technology, but also in generating new firms. Specifically speaking, public research institute is traced not only as the source of initial capabilities for emerging firms, but it has become an important actor in industrial innovation system, especially for a knowledge intensive industry, such as biotechnology.

Interviews with key policy-makers also support the above findings. Our judgment is that policy-makers in Taiwan have a deep understanding of the special requirements of biotechnology. They are presently more inclined than ever to devise policies aimed to stimulate the interaction, communication, and collaboration among those institutions involved in knowledge production, diffusion and application. This finding is consistent with the view of some authors that the development of DBFs relies on the knowledge center for public science (Narin et al., 1998; Biese and Stahl, 1999; McMillan et al., 2000), and the interaction among institutions (OECD, 1997; Oliver and Liebeskind, 1997/1998; Momma and Sharp, 1999).

Our analysis has some limitations: First, the results of this paper do not answer the questions about the effectiveness of each policy tool definitively, but they do allow us to analyze the contribution of each policy tool relatively. Second, we do not select by prioritizing these policy tools as MCDM method usually does because the technology development generally involved a mixture of policy tools, the exact mix varying with country context and the capabilities of its policy-makers. But the results are highly suggestive for policy-making. Regardless, this paper should be considered as a preliminary work toward understanding the effect and the effectiveness of policy tools on the development of biotechnology industry.

Appendix 1. Seventeen policy tools of the Taiwanese Government for biotechnology

a. Applied research programs: R&D programs sponsored by Ministry of Economic Affairs (MOEA) for developing and transferring technologies that are generic and critical for emerging industries.
b. Assisting programs for new product development: Programs sponsored by the Industrial Development Bureau of MOEA for encouraging domestic enterprises to develop new products with financial aid and technical assistance.
c. Information Service Programs: Information services provided by government's agencies, mainly by Industrial Technology Information Service (ITIS) program, including market intelligence and technology foresight.
d. Basic research programs: Programs that are mostly funded by National Science Council include national-level S&T projects and academic projects in universities.
e. Enhancement of educational systems: Government encourages universities to establish biotechnology education centers, upgrade their research capability, and recruit world class professors.
f. Alternative programs for military service: Males with advanced degrees may join a selected research organization and do research work for 4 years instead of 2 years of military service.
g. Training programs: Government-supported training programs in upgrading and expanding the human resources available for biotechnology industry.
h. Overseas recruiting programs: Funding programs for encouraging private sectors to recruit experienced technical people from abroad.
i. Research institutes: Research institutes sponsored or owned by the government, such as the Industrial Technology Research Institute, Development Center of Biotechnology, and Academic Sinica.
j. Promotion teams: Task forces or committees organized by the government to coordinate efforts from different ministries and monitor the progress of implementing governmental policies.
k. S&T basic law: According to the Basic Law for Science and Technology Development, the intellectual properties generated from public-funded research were delegated to research organizations to encourage their application, similar to the Bayh-Dole Act of the US.
l. Biotechnology parks: The establishment of biotechnology parks, including the Science Park in Chu-Nan and the Technology Park in Tai-Nan.
m. Clinical infrastructure development: Establishment of clinical system and infrastructure for new drug development, including streamlining the process for review and approval of new drugs, establishing new drug clinical trial center, and establishing a clinical trial system for Chinese medicine.
n. Direct investment: Government invests in biotechnology firms through various means, including the operation of a state-owned enterprise and investment from government-owned funds.
o. Incubating programs: Programs to establish incubator facilities in universities, research institutes and industrial parks.
p. Databases and information support: Database and computing software supported by government for public use.
q. Financial incentives: Financial incentives, such as tax allowances or deductions for companies or persons in biotechnology industries; Development Fund and Small–Medium Enterprise Development Fund provided for multiple ventures.

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