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Risk Sharing in the Commercialization Step of National R&D Project

Kyeong-Hee Han *
Soung Hie Kim *

Abstract

Nations, especially developing countries, hope to license the technology developed at the expense of government Research and Development (R&D) investment to the corresponding firms for commercial exploitation. Since commercial process is owing to lots of risk, firms have to grope the possibility of forming a partnership in order to reduce the risk. Therefore, a joint venture between firms would be needed to share the risk.

This methodology suggests a way that probabilistic information of commercial project payoffs can be obtained using experts in project evaluation committee and the ratio of individual firm's investment size can be derived using risk sharing concept. Also simple examples are given.

1. Introduction

The direction in which research on R&D decision making has moved is toward the construction of objective functions which are capable of representing multiple objectives under either certain or uncertain conditions. Risk sharing is the motivating force for many institutional arrangements and markets. Joint venture with substantial risk leads to joint ownership arrangements in order to share the risk.

Technology transfer from government to firms comprises complex process and the successful transfer is dependent on a host of variables ranging from need identification, the calibre of the research them, and adequate financial and management support, to the existence of a supporting infrastructure which encourages the development and transfer of governmental technology to aid industry development. Canadian experience case studies[2] points to crucial factors in the successful transfer of technology. And SAPPHO study[8] clearly demonstrates the importance of a marketing approach to innovation. Commercial projects are risky. Commercial projects mean industrial project transferred from government to industry. To evaluate commercial project successfully, one must examine the project as through as

* Korea Advanced Institute of Science and Technology.

possible. The sound project must have first, a property dubbed "Inherent Merit" and second, an "Environment" in which the project can flourish.[6] Among various factors related to successive transfer of government's technology, the factors related to marketing and sales are critical.

This methdology suggests how to obtain aggregated probabilistic information of commercial project payoffs in the commercialization step of national R&D project under the situation that government has constructed a project evaluation committee composed with experts and how to determine the ratio of individual firm's investment size to reach Pereto optimality in a joint venture, using risk sharing concept.

2. Probabilistic Information of Commercial Project Using Expert Committee

A project under uncertainty may be characterized by its random variables. Among various variables related to marketing and sales, one of the most crucial variables is cash flow. Cash flow in the future must be estimated by experts possessing the necessary subjective expertise.

Consider a stream of such cash flows, X_{it}, generated by a particular expert i ($i = 1,2, \ldots, m$) in period t ($t = 0, 1, \ldots, n$) and denote that X_{it} is the net cash flow, resulting from all possible inflows and outflows at any particular time t by evaluated expert i.

Mean and variance for the net cash flow can be estimated from the assessed X_{it} values. One rather straightforward way of obtaining the mean and variance for cash flow is based on the properties of the bata- distribution in PERT[9]. This method requires that the expert makes a pessimistic estimate, a_{it}, a most likely estimate, m_{it}, an optimistic estimate, b_{it}, for each cash flow in period t. Thus a net present value of each three-level estimate is as follows:

$$a_i = \sum_{t=0}^{n} \frac{a_{it}}{(1+d)^t}, \quad m_i = \sum_{t=0}^{n} \frac{m_{it}}{(1+d)^t}, \quad b_i = \sum_{t=0}^{n} \frac{b_{it}}{(1+d)^t} \tag{1}$$

where d is an interest rate.

Then, mean and variance of the net cash flow evaluated by expert i are obtained from the following equations, respectively.

$$u_i = (a_i + 4m_i + b_i)^2/6$$
$$\sigma_i^2 = (b_i - a_i)^2/36$$

where u_i = mean cash flow evaluated by expert i.
σ_i^2 = variance of cash flow evaluated by expert i.

Because the random variable of beta-distribution is scaled from 0 to 1, three-level estimates, a_i, m_i, b_i, should be scaled between 0 and 1. Also, Scaled values shall be converted original values. Let $\bar{a}_i$, $\bar{m}_i$, $\bar{b}_i$ represent three-level values scaled between 0 and 1:

In order to aggregate experts' assessments, we use the characteristic of nature-conjugate distribution [3], that is, if the prior distribution is a member of a nature-conjugate family of distributions, then the posterior is a member of the same family.

The beta-distribution of random variable p ($0 \leqslant P \leqslant 1$) is the following form.

$$f_b(p) = \frac{(n-1)!}{(r-1)!\,(n-r-1)!}\; p^{r-1}(1-p)^{n-r-1} \tag{2}$$

where $0 \leqslant p \leqslant 1$, $0 < r < n$.

Parameters of beta-distribution are r and n. If two expert's priors are beta-distributions (r, n) and (r′,n′), respectively, consensus distribution would be a beta-distribution (r″,n″), where $r'' = r+r'$ and $n'' = n+n'$.

Suppose that $f_i(p)$ is a beta-distribution with r_i and n_i, $i = 1, \dots, m$. Then, $f_b(p)$ would be a beta-distribution with parameters $r = \sum_{i=1}^{m} w_i r_i$ and $n = \sum_{i=1}^{m} w_i n_i$, by weighting and combining $f_i(p)$'s through Bayes' rule. Suppose that the judgement of m experts are independent, in other words, no overlapping of information. Upper limit of $\sum_{i=1}^{m} w_i$ should be m. On the other hand, suppose that the judgements of m experts are identical, lower limit should be one. Thus, the value of $\sum_{i=1}^{m} w_i$ is required to exist between one and m. In most cases, the sum of the weights is closer to one than to m.

We can estimate the parameters of the beta-distribution using the following relationship:

$$\bar{u}_i = \frac{r_i}{n_i}, \quad \sigma_i^2 = \frac{r_i(n_i - r_i)}{n_i(n_i+1)} \tag{3}$$

where $n_i = \bar{u}_i(1-\bar{u}_i)/\sigma_i^2 - 1$

$r_i = \bar{u}_i[\bar{u}_i(1-\bar{u}_i)/\sigma_i^2 - 1]$

Thus, if the distribution of each expert i is $f_i(p) = f_b(p|r_i,n_i)$, the consensus distribution is a beta-distribution with parameters $r = \sum_{i=0}^{m} w_i r_i$ and $n = \sum_{i=0}^{m} w_i n_i$. Next step is to discretize a consensus beta-distribution f(p) in order to apply lottery structure to be appeared in the following section. Discretization can be performed by the following relationship:

$$\int_p^1 \frac{(n-1)!}{(r-1)!(n-r-1)!} z^{r-1}(1-z)^{n-r-1} dz = \sum_{x=0}^{r-1} \binom{n-1}{x} p^x (1-p)^{1-x} \tag{4}$$

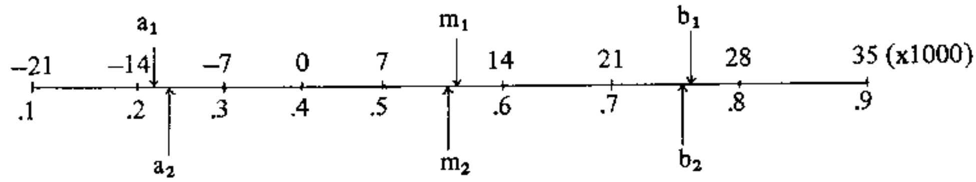
For example, the following hypothetical table shows the three-level estimates for two experts.

Period	Expert 1			Expert 2		
t	a_{1t}	m_{1t}	b_{1t}	a_{2t}	m_{2t}	b_{2t}
0	\$–20,000	\$–10,000	\$ –6,000	\$–20,000	\$–12,000	\$ –5,000
1	–6,000	2,000	6,000	–4,000	1,000	4,000
2	6,000	12,000	18,000	6,000	14,000	17,000
3	12,000	18,000	28,000	10,000	18,000	30,000

Suppose that the minimum attractive rate of return is 20%, three level estimates of the total discounted sum are as follows:

level	Expert 1	Expert 2
a	\$–13,889	\$–13,372
m	10,655	8,972
b	27,704	27,500

Here, we should scale a, m, b, as follows:



And three-level estimates can be scaled as follows:

level	Expert 1	Expert 2
$\bar{a}$	.2016	.2089
$\bar{m}$	.5562	.5282
$\bar{b}$	.7958	.7929

Scaled mean and variance of the cash flow are

$\bar{u}_1 = (\bar{a}_1 + 4\bar{m}_1 + \bar{b}_1)/6 = .5344, \quad \bar{u}_2 = .5191$

$\bar{\sigma}_1^2 = (\bar{b}_1 - \bar{a}_1)^2/36 = .0098, \quad \bar{\sigma}_2^2 = .0095$

Using (3) the parameters of the beta-distribution are estimated as follows:

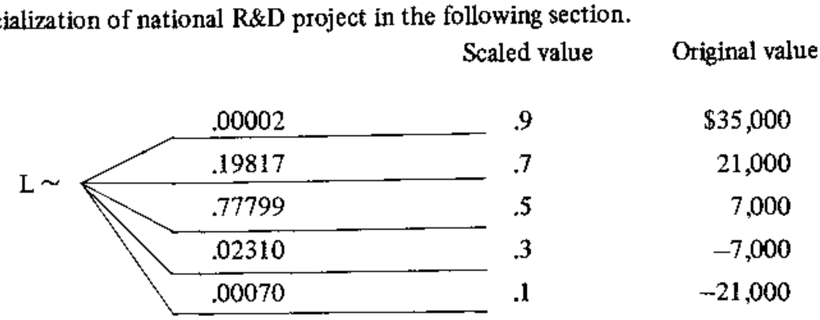
$n_1 \doteqdot 24, \ r_1 \doteqdot 13, \ n_2 \doteqdot 25, \ r_2 \doteqdot 13.$

Suppose that experts' judgements are independent. Then, we set $\sum_{i=1}^{2} w_i = 2$ and each w_i one. The consensus distribution f(p), is a beta-distribution with parameters $r = 26, n = 49$.

For later use in a lottery, discretize this consensus distribution using (4). Then, we obtain the followings:

Interval	Median	Probability
.8 – .99	.9	.00002
.6 – .8	.7	.19817
.4 – .6	.5	.77799
.2 – .4	.3	.02310
.01 – .2	.1	.00070

Therefore, we obtain the following lottery to be used as payoff matrix estimated in process of commercialization of national R&D project in the following section.



3. Determining the Ratio of Individual Firm's Investment Using Risk Sharing

Government hopes to earn on the developed technology by licensing it to firms for commercial exploitation. However, another problems may arise from firm's pointview. That is, commercial process is owing to risk. The firm will have to grope the possibility of forming a partnership. Risk sharing is the motivating force for many institutional arrangements and markets. Different partners may have different attitude toward risk and preference concerning the division of partnership's payoff.

Here we are interested in joint venture of firms. That is, although a firm has enough resources to undertake the entire project, but is interested in pursuing the possibility of forming a partnership to share the risk. Suppose that the payoff is shared in direct proportion to the percentage of investment plus side payment. The more risk averse firm receives smaller payoff but will be compensated by receiving a positive side payment from another firm.[4]

Consider the case that there are several firms in joint venture and lotteries having more than two payoffs. Let lottery 1 be a lottery that pays off y_1 if state s_1 occurs, . . . , y_m if states s_m occurs. Let the states $s_1, s_2, \ldots, s_m$ have probabilities $p_1, p_2, \ldots, p_m$, respectively. Denote n members of the joint venture by 1, 2, . . . , n. A partition of lottery 1 describes for state s_k how joint payoff y_k will be split between individual firms. The following table shows these notations:

Lottery 1			Partition of 1
State	Probability	Payoff	1 --- i --- n
s_1	p_1	y_1	x_{11} --- x_{1i} --- x_{1n}
–	–	–	– – –
–	–	–	– – –
s_k	p_k	y_k	x_{k1} --- x_{ki} --- x_{kn}
–	–	–	– – –
–	–	–	– – –
s_m	p_m	y_m	x_{m1} --- x_{mi} --- x_{mn}

From government's viewpoint, we are interested in each member's preference concerning entire vector y_k, not just member's preference for his own payoff. This enables each firm to express its preference about its own payoff in the relation to the payoffs received by the other n-1 group member firms.

Assume that each group member assesses a cardinal utility function for y_k. Member i's utility function is denoted by $u_i(y_k)$. Next step is to form a group utility function $u_g(y_k)$. Treat it as a constrained maximization problem:

$$u_g(y_k) = \max_{y_k} u_g(y_k) \quad \text{such that} \quad \sum_{i=1}^{n} x_{ki} = y_k \tag{5}$$

Denote y_k at which u_g is maximized for a given y_k by $x_k^*(y_k)$. If $x_k^*(y_k)$ is considered as a function of y_k, it traces out the optimal sharing rule for all values of y_k. A linear rule

$$u_g(y_k) = \sum_{i=1}^{n} \lambda_i u_i(y_k) \tag{6}$$

with $\lambda_i > 0$ for $i = 1, 2, \ldots, n$, is appealing in the sense that it is the only rule which guarantees that the resulting decision under uncertainty will be Pareto optimal in utility-space. The most commonly used types of multiattribute utility function are additive form and additive group utility function. [5]
Utility function of member i for y_k is said to be additive if it can be expressed as follows:

$$u_i(y_k) = \sum_{j=1}^{n} k_{ij}u_{ij}(x_{kj}) \tag{7}$$

where u_{ij} is a conditional utility function of member i for x_{kj} and k_{ij} is a positive scaling constant for $i, j = 1, 2, \ldots, n$.
Utility function for y_k is additive if and only if elements of y_k are additive independent. Focus on the implication of group utility function u_g that can be expressed in additive form:

$$u_g(y_k) = \sum_{j=1}^{n} k_{gj}u_{gj}(x_{kj}) \tag{8}$$

where u_{gj} can be interpreted as a cardinal group utility function for x_{kj} and $k_{gj} > 0$ for $j = 1, 2, \ldots, n$. Formally if u_i is given by (7) for $i = 1, 2, \ldots, n$ and if linear rule in (6) is used to generate u_g, then,

$$u_g(y_k) = \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_i k_{ij} u_{ij}(x_{kj}) = \sum_{j=1}^{n} k_{gj}u_{gj}(x_{kj}) \tag{9}$$

where $k_{gj} = \sum_{i=1}^{n} \lambda_i k_{ij}$

and $u_{gj}(x_{kj}) = \sum_{j=1}^{n} \lambda_i k_{ij} u_{ij}(x_{kj}) / \sum_{i=1}^{n} \lambda_i k_{ij}$

Generally, k_{ij} might be considered to represent the power of member j in joint venture as judged by member i. The same interpretation in terms of group preferences can be given to k_{gj}.
Scale utility function such that

$$u_{gj}(x^o_{kj}) = u_{ij}(x^o_{kj}) = u_g(y^o_k) = u_i(y^o_k) = 0 \tag{10}$$

and $$u_{gj}(x^+_{kj}) = u_{ij}(x^+_{kj}) = u_g(y^+_k) = u_i(y^+_k) = 1 \tag{11}$$

for $i, j = 1, 2, \ldots, n$, where $y^o_k = (x^o_{k1}, \ldots, x^o_{kn})$ and $y^+_k = (x^+_{k1}, \ldots x^+_{kn})$. Equations (7), (8), (10), and (11) imply $\sum_{j=1} k_{ij} = 1$ and $\sum_{j=1} k_{gj} = 1$. Also scaling restriction implies that the sum of coefficients of linear aggregation function should be unit: $\sum_{i=1}^{n} \lambda_i = 1$.

We will characterize optimal sharing rule and group utility function for y_k when u_g is additive. In order to derive group's risk attitude, assume that $u_{ij}(x_{kj})$ and $u_{gj}(x_{kj})$ are twice differentiable for all j's and define Pratt-Arrow risk aversion function [1] as follows:

$$r_{ij}(x_{kj}) = -u''_{ij}(x_{kj})/u'_{ij}(x_{kj}) \tag{12}$$

$$r_{gj}(x_{kj}) = -u''_{gj}(x_{kj})/u'_{gj}(x_{kj}) \tag{13}$$

$$r_g = -u''_g(y_k)/u'_g(y_k) \tag{14}$$

where r_{ij} and r_{gj} represent risk aversion function of member i and group for the payoff to member j, respectively, and r_g represents group's risk aversion function for group payoff y_k.
Proposition: If u_g is twice differentiable, additive with u_{gj}, and $r_{gj} > 0$ for $j = 1, 2, \ldots, n$, then

$$\partial x^*_j(y_k) / \partial y_k = (r_{gj}(x^*_j(y_k)))^{-1} \left(\sum_{i=1}^{n} (r_{gi}(x^*_i(y_k)))^{-1} \right)^{-1}. \tag{15}$$

(Proof is shown in Appendix.)

From (15), the rate of increase of member j's share of y_k increases as r_{gj} decreases with r_{gi} held constant for j = i.

Next, consider the expected utility. Expected utility u_i of individual firm i can be obtained as follows:

$$\bar{u}_i = p_1 u_i(y_1) + p_2 u_i(y_2) + \ldots + p_m u_i(y_m)$$

$$\text{where} \quad u_i(y_1) = k_{i1}u_{i1}(x^*_{11}) + \ldots + k_{in}u_{in}(x^*_{1n})$$

$$u_i(y_2) = k_{i1}u_{i1}(x^*_{21}) + \ldots + k_{in}u_{in}(x^*_{2n})$$

$$- \quad - \quad -$$

$$- \quad - \quad -$$

$$u_i(y_m) = k_{i1}u_{i1}(x^*_{m1}) + \ldots + k_{in}u_{in}(x^*_{mn})$$

For illustration, consider a joint venture of two firms and three s_j's case. Suppose that individual firm's utility function is independent on the other's and it has an exponential form.

$$\text{Then,} \quad u_i(y_k) = k_{i1}(a_1 - b_1 e^{-c_1 x_{k1}}) + k_{i2}(a_2 - b_2 e^{-c_2 x_{k2}})$$

$$\text{for } i = 1, 2, \; k = 1, 2, 3, \; c_1 > 0, c_2 > 0.$$

From (9), group utility function for y_k is the form:

$$u_g(y_k) = k_{g1}(a_1 - b_1 e^{-c_1 x_{k1}}) + kg_2(a_2 - b_2 e^{-c_2 x_{k2}})$$

where $k_{gi} = \lambda_1 k_{1i} + \lambda_2 k_{2i}$, for i = 1, 2.

We can solve the constrained maximization problem by using Lagrange function. Maximizing $u_g(y_k)$ with constraint $x_{k1} + x_{k2} = y_k$ yields

$$x^*_{k1}(y_k) = (c_2/c_1 + c_2)y_k + (c_1 + c_2)^{-1} \ln(k_{g1}b_1c_1/k_{g2}b_2c_2)$$

$$x^*_{k2}(y_k) = (c_1/c_1 + c_2)y_k - (c_1 + c_2)^{-1} \ln(k_{g1}b_1c_1/k_{g2}b_2c_2)$$

Here, c2/ (c1 + c2) represents the proportion of y that firm 1 receives and $(c_1 + c_2)^{-1} \ln(k_{g1}b_1c_1/k_{g2}b_2c_2)$ represents a side payment from firm 2 to firm 1.

Note that the proportional division of y depends only two risk aversion measures, $r_{g1}(x^*_{k1}(y_k)) = c_1$ and $r_{g2}(x^*_{k2}(y_k)) = c_2$, not on the scaling constant.

For illustrative purpose, the following table shows the simplified lottery obtained from the previous section.

Lottery 1		Partition of 1	
Probability	Payoff	Firm 1	Firm 2
.22	$21,000	x11	x12
.78	7,000	x21	x22

First, in order to derive firm's utility function, the following procedure is necessary. This study shows one of the simple procedures, based on 50-50 gambles with basic reference gamble and constant risk aversion. Constant risk aversion implies a utility curve of the form $u(x) = a - be^{-\lambda x}$, where x is the random payoff measured in terms of the evaluation units and $b > 0$. When we set $u(x_{min}) = 0$ and $u(x_{max}) = 1$, only one more equation is needed to find values of parameters a, b, and λ. This means that single assessment of certainty equivalent(CE) is all that required to specify completely the preference curve. When we use 50-50 gamble, we have $u(CE) = .5u(x_{max}) + .5u(x_{min})$. From this and the requirement that $u(x_{max}) = 1$ and $u(x_{min}) = 0$, we obtain parameters from the following equations:

$$e^{-\lambda(CE)} = .5(e^{-\lambda(x_{min})} + e^{-\lambda(x_{max})})$$
$$a = e^{-\lambda(x_{min})} / (e^{-\lambda(x_{min})} - e^{-\lambda(x_{min})})$$

For example, using 50–50 gamble technique, we can obtain CE by finding indifference value to the lottery for each firm, respectively.

(Firm 1 : More risk-averse)

5000 ~ [.5: \$30,000; .5: −7,000]

(Firm 2 : Less risk-averse)

7000 ~ [.5: \$30,000; .5: −7,000]

And using the above equations related to parameter estimation, we obtain the following utility functions:

Firm 1 : $u(x) = 1.564 - 1.2120e^{-.0000255x}$

Firm 2 : $u(x) = 2.358 - 2.0547e^{-.0000138x}$

Next step is to determining k_{gj}. The k_{gj} might be considered to represent the importance or the power of firm j as judged by the joint venture. Applying the eigenvector method based on pairwise comparision[7] we directly obtain $k_{g1} = .483$ and $k_{g2} = .517$. Thus, optimal sharing rule would be as follows:

$$x_{11}^*(y_1) = (c_2/c_1 + c_2)y_k + (c_1 + c_2)^{-1} \ln(k_{g1}b_1c_1/k_{g2}b_2c_2)$$
$$= 7374 + 462 = 7386$$

$$x_{12}^*(y_1) = 13626 - 462 = 13164,$$
and $x_{21}^*(y_2) = 2458 + 462 = 2920$, $x_{22}^*(y_2) = 4542 - 462 = 4080$.

In conclusion, Firm 1 and 2 invest 35.1% and 64.9% of total investment, respectively. Of course, Firms may share payoffs at the rate of the total investment size and side payment. The more risk averse firm receives a smaller share of y, but will be compensated by receiving positive side payment.

4. Conclusion

This study considers a joint venture problem occurring in commercialization step of national R&D project developed by government. After deriving the probability information of payoffs related to a project, ratio of individual firm's investment size is obtained from risk sharing concept.

In the real world the successful application of this methodology still faces two difficulties: exact assessment of each firm's utility function and full consideration of other real factors including risk preference.

APPENDIX
PROOF OF PROPOSITION

The first order condition for optimality is $k_{gi}u'_{gi}(x^*_{ki}) = h$, $i = 1, 2, \ldots, n$, where the prime denotes differentiation, the argument y_k of x^*_{ki} is omitted for notational simplicity, and h is a Lagrange multiplier such that $h = u'_g(y_k)$. Thus, $k_{gi}u'_{gi}(x^*_{ki}) = u'_g(y_k)$. Differentiating with respect to y_k yields $k_{gi}u''_{gi}(x^*_{ki})(\sigma x_{ki}/\sigma y_k) = u''_g(y_k)$, and dividing the new equation by the preceding equation shows

$$(\sigma x^*_{ki}/\sigma y_k)r_{gi}(x^*_{ki}) = r_g(y_k) \text{ or } r_g(y_k)/r_{gi}(x^*_{ki}) = (\sigma x^*_{ki}/\sigma y_k).$$

Summing over i yields $r_g(y_k) \sum_{i=1}^{n} (r_{gi}(x_{ki}))^{-1} = 1$, which proves $r_g(y_k) = (\sum_{i=1}^{n} (r_{gi}(x^*_{ki}(y_k)))^{-1})^{-1}$. Substituting this in $r_g(y_k)/r_{gi}(x^*_{ki}) = (\sigma x_{ki}/\sigma y_k)$, we obtain (15). Q.E.D.

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