Technological Innovation Studies Program

Research Report

Assessment of R&D Project
Evaluation and Selection Procedures

by:
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Rapport de recherche

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INTRODUCTION

The following three reports dealing with R&D project evaluation and selection decision processes resulted from a single grant to the authors. They are put together under one cover for the convenience of the readers.

REPORT 1

INFORMATION PREFERENCES AND ATTENTION PATTERNS IN THE R&D INVESTMENT DECISIONS

ABSTRACT:

One hundred and thirty-two Canadian executives participated in a study of information preferences in R&D decision making.The subjects were asked to rate items from a comprehensive information basket perceived by them important in R&D decision making. Relationships between information preference profiles and executive and firm attributes were investigated. The study concludes with some suggestion for increase fit between inducement strategies and target populations.

RESUME

Cent trente-deux dirigeants canadiens ont collaboré à une enquête sur les préférences en matière de renseignements servant à orienter les choix de R et D. On leur a demandé de classer par ordre de préférence une vaste gamme d'éléments d'information qu'ils considèrent importants lors d'une prise de décision en matière de R et D. On a étudié les rapports entre les choix de renseignements, les dirigeants et les caractéristiques de l'entreprise. L'étude fait, en conclusion, quelques suggestions pour resserrer les liens entre les choix et les populations visées.

REPORT 2

MULTI-ATTRIBUTE INVESTMENT DECISIONS: A STUDY OF R&D PROJECT SELECTIONS

ABSTRACT:

In evaluating R&D opportunities executives make tradeoffs among three classes of attributes: commitment of resources,expected payoff and risk. The focus of this study of Canadian top executives and R&D managers is the investigation of these tradeoffs and how they differ among executives and industries. On the basis of judgments of sixty hypothetical projects, alternative individual and group models were estimated using regression and discriminant analysis procedures. The results indicate that linear models provide good fit with observations of R&D investment judgments and that differences in tradeoffs between risk and rates of return can be related to the characteristics of the executives and their environments.This information is useful for predicting R&D investment portfolios in an environment of changing opportunities.

RESUME:

Les dirigeants d'entreprises considèrent trois types de facteurs lorsqu'ils étudient les débouchés en matière de R et D: l'investissement, les bénéfices escomptés et les risques. La présente étude porte sur les hauts dirigeants canadiens et les responsables de R et D; elle met l'accent sur les divers choix formulés par les hauts dirigeants et les industriels canadiens. On a demandé les avis sur soixante cas hypothétiques et étudié divers modèles portant sur des cas individuels, et collectifs à l'aide de méthodes d'analyse régressive et discriminatoire. Les résultats révèlent que les modèles linéaires se prêtent bien à l'étude des choix d'investissements en matière de R et D, et que les divergences d'opinion au sujet de l'évaluation des risques et profits dépendent du type de dirigeant et du milieu de travail. Cette étude permet de prévoir les portefeuilles d'investissement de R et D dans un contexte où les débouchés varient.

REPORT 3

R&D PROJECT EVALUATION: FROM FIRM BEHAVIOUR TO NORMATIVE MODELS TO IMPLEMENTATIONS

ABSTRACT:

This paper analyzes available information about determinants and practices of R&D investment decisions, describes the inventory of normative models developed to improve decision making, and identifies emperical studies investigating their implementation. Review of the state of art leads to the identification of four areas of information which are deficient.

RESUME

La présente étude analyse les renseignements dont nous disposons sur les facteurs et modes de décision pour les investissements de R et D; elle décrit les modèles normatifs élaborés pour améliorer les prises de décision et énumère les études empiriques sur l'application de ces dernières. Un examen général permet de distinguer quatre domaines où les renseignements sont insuffisants.

FACULTY OF COMMERCE

AND BUSINESS ADMINISTRATION

Information Preferences and Attention Patterns in R & D Investment Decisions

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INTRODUCTION

Simon and others have argued that firms make decisions on the basis of partial knowledge (e.g. see March and Simon 1958, Cyert and March 1963). High costs associated with obtaining and processing information, constrained computational abilities and limited spans of attention induce the development of search heuristics. These heuristics are often institutionalized in the form of standard operating procedures for the selection and evaluation of alternatives.

The problem of R & D project selection constitutes one of the more complex areas for firm decision making. It deals with risky alternatives, the outcomes of which are realized over a long time horizon and are subjected to risks from both internal and environmental sources.

The importance of information preference and attention patterns for R & D policies are often ignored. Generally, the focus of R & D inducement policies has been upon creating economic incentives or direct investment in R & D. Attempts to employ information strategies to induce R & D seem to ignore the fact that what is good news to some is no news to others. By identifying differences in information attended to, strategies and interventions to create favorable climates for R & D can be designed to fit specific target populations, thereby increasing their potential impact.

In this study, we focus upon empirical investigation of information preferences and attention patterns in R & D decision-making.

In particular, the association of preference and attention patterns to decision makers' attributes is investigated.

METHODOLOGY

On the basis of extensive literature search, an "information basket" was constructed, combining dimensions judged relevant to R & D decision-making, according to a variety of normative perspectives and behavioral theories. The "information basket" was used as a basis for constructing a questionnaire to solicit preferences for information items. A sample of executives was asked to indicate preferences for information. Analysis of these responses to identify relationships between preferences and individual and organizational attributes was conducted.

In the following sections concerning the methodology, we provide details on -

(1) the construction and a-priori justification of the "information basket",

(2) the questionnaire,

(3) the sample,

(4) the confirmation of the a-priori information dimensions and testing of the relevance of the questionnaire items.

Construction of the information basket

Information items were selected after a review of the R & D, general economic and decision making literatures. Table 1 lists the items and their sources in the literature. The items were classified into six general dimensions: general economic trends and expectations, government role in the economy, information, market, firm and project attributes.

Insert Table 1
about here

The Questionnaire

Forty-seven items were selected to represent the various sub-dimensions in the information basket. Subjects were asked to rate their importance on a seven point Likert scale. In addition, subjects were requested to provide biographical information on themselves, and extensive information about their firms. An itemized list is provided in Table 2, with the appropriate abbreviation to be used when results are reported.

Insert Table 2
about here

The Sample

A sample of 330 of executives was randomly selected from the directory of R&D establishments in Canada (Ministry of State for Science and Technology, 1974) plus the remainder of 'Top 100' firms (Morgan, 1975) not included in the R & D directory. A second mailing was sent to replace those firms which had declined to participate. Reminders were sent to those firms which had not responded initially. The questionnnaire was sent to the R & D director or to the president of the firm. The response rate was 40%. The response distribution corresponds well with the population distribution indicating that the sectoral breakdown in the sample is representative of R & D establishment frequencies in the population.

Table 1

Variables Relevant for R & D Decision Making

Concept	Item	Source
ECONOMY, GENERAL		
Past & Current Trends	average profit rate in the economy short term bank interest rates* stock market trends* general trends in inventories general trends of growth unemployment	Keynes (1964), Galbraith (1973), Preston (1975), Trendicator (Raguley and Booth, 1975), U.S. Department of Commerce (1975)
Demand Changes	expected growth of real GNP growth of population	Schumpeter (1971) Quinn (1966), Bright (1970)
Inducements to Change	expected wage settlements expected general productivity changes expected rate of inflation expected energy requirements	Schmookler (1966), Rosenberg (1974), Kamien & Schwartz (1968), Fellner (1971), Hamien & Ruttan (1970)
Demand and Cost Changes	expectations with respect to the foreign exchange rate	Leonard (1971)
ECONOMY, GOVERNMENT ROLE		
Costs, Direct	government subsidies for R&D projects* low interest government loans for R&D projects* possibility of gaining a new government contract for part of the project* favourable tax policies for R&D projects	Tilton (1971), Brooks (1972), Quinn (1966), Hamberg (1966) Leonard (1971), Foster (1971), Arrow (1962)
Costs, Indirect	accelerated depreciation of R&D expenditures for tax purposes accelerated depreciation of new capital equipment expenditures for tax purposes*	Hamberg (1966)
	low interest rates on government bonds high interest rates on government bonds interest rates on government bonds increasing interest rate on government bonds declining	Keynes (1964), Galbraith (1973)

CONTINUED

Table 1 (Continued)

Concept	Item	Source
Information	government funding of feasiblity studies for R&D projects* availability of sound government information on technological change* government support and promotion for market development availability of government surveys of market potential*	Thurston (1971), Brooks (1972), Bright (1968), Foster (1971), Drucker (1975)
Market Influence	growth of government expenditures favourable tariff policy pollution control measures (environmental concern)	Bright (1968), Foster (1971) Thurston (1971), Smith (1973)
INFORMATION		
Private	availability of private surveys of market potential	Thurston (1971), Brooks (1972), Bright (1968), Foster (1971), Drucker (1975)
Government	availability of government surveys of market potential* availability of sound government information on technological change*. government funding of feasibility studies for R&D projects*	
MARKET		
	average profit rate of industry group	
	stability of market	Ansoff & Stewart (1967)
	barriers to entry in the market	Mansfield (1969), Schumpeter (1971), Scherer (1971), Comanor (1967), Williamson (1965), Baldwin & Childs (1969), Cooper (1966), Galbraith (1973)
FIRM		
Demand	recent growth of sales of firm expected growth of sales of firm	Lithwick (1969), Leonard (1971), Mansfield (1968), Hamberg (1966)
	stage in life cycle of existing products	Kotler (1967), Quinn (1966), Tilles (1966), Ansoff and Stewart (1967)
Supply, Factors	availability of scientifically trained personnel	Brooks (1972), Cooper (1966)
Liquidity	average profit rate of firm accelerated depreciation of new capital equipment expenditures for tax purposes* short term bank interest rates* stock market trends* government subsidies for R&D projects* low interest government loans for R&D projects*	Scherer (1971), Williamson (1965), Galbraith (1973) Cyert & March (1963), Mansfield (1968), Hamberg (1966), Tilton (1971), Brooks (1972)

CONTINUED

Table 1 (Continued)

Concept	Item	Source
Innovativeness	history of success with R&D (firm's)	Ansoff & Stewart (1967)
PROJECT		
Commitment, Money and Resources	cost of the R&D project relative to total sales of firm	Mansfield (1964), Scherer (1971), Gerstenfeld (1971), Cooper (1966), Tilles (1966), Ansoff & Stewart (1967), Mottley & Newton (1959), Allen (1970)
	possibility of gaining a new government contract for part of the project*	Brooks (1972), Tilton (1971), Hamberg (1966)
Commitment, Time	expected payback period for the R&D project	Leonard (1971), Mansfield (1968), Gerstenfeld (1971), Bright (1968), Kotler (1967), Ansoff & Stewart (1967) Brooks (1972), Tilles (1966), Cooper (1966), Allen (1970), Hamberg (1963)
Profitability	rate of return for the R&D project	Mansfield (1969), Disman (1962), Quinn (1966), Kotler (1967 Peterson (1967), Allen (1970)
	expected impact of the R&D project on market share	Mansfield (1968), Peterson (1967), Mottley & Newton (1959)
	expected change in sales attributed to R&D project	Peterson (1967)
Risk	probability of technical success estimated for the R&D project	Scherer (1971), Mansfield (1968), Nelson (1959), Gerstenfeld (1971), Disman (1962), Quinn (1966), Ansoff Stewart (1967), McGlauchlin (1968), Thurston (1971), Allen (1970), Cooper (1966), Tilles (1966), Cranston (1974), Mottley and Newton (1959)
	patentibility of innovation	Phillips (1966), Scherer (1971), Ansoff (1965), Mansfield (1968), Quinn (1966), Foster (1971)

*indicates items that appear in more than one dimension.

Table 2: INFORMATION ITEMS

ACCL DEPR	accelerated depreciation of new capital equipment expenditures for tax purposes
AC DEPR RD	accelerated depreciation of R&D expenditures for tax purposes
AV PR ECON	average profit rate in the economy
AV PR FIRM	average profit rate of firm
AV PR GRP	average profit rate of industry group
BAR TO ENT	barriers to entry in the market
COST SLS	cost of the R&D project relative to total sales of firm
D I GOVT B	interest rate on government bonds declining
EXP E REQ	expected energy requirments
EXP GNP GR	expected growth of real GNP
EXP INFL	expected rate of inflation
EXP PAY B	expected payback period for the R&D project
EXP PRD CH	expected general productivity changes
EXP SLS GR	expected growth of sales of firm
EX W SETTL	expected wage settlements
FAV TARIF	favourable tariff policy
FAV TX POL	favourable tax policies for R&D projects
FEAS STUD	government funding of feasibility studies for R&D projects
FOR EXCH R	expectations with respect to the foreign exchange rate
GEN TRD GR	general trends of growth
GOV EXP GR	growth of government expenditures
GOV INF CH	availability of sound government information on technological change
GOV SUP MK	government support and promotion for market development
GOVT SUBS	government subsidies for R&D projects
GOVT SURV	availability of government surveys of market potential
H I GOVT B	high interest rates on government bonds
I I GOVT B	interest rates on government bonds increasing
INVENT TR	general trends in inventories
LIFE CYCL	stage in life cycle of existing products
L I GOVT B	low interest rates on government bonds
L I GOVT L	low interest government loans for R&D projects
PATENTS	patentibility of innovation
P GOVT CON	possibility of gaining a new government contract for part of the project
POLL CONT	pollution control measures (environmental concern)
POP GR	growth of population
PRIV SURV	availability of private surveys of market potential
P TECH SUC	probability of technical success estimated for the R&D project
REC SLS GR	recent growth of sales of firm
RD HISTRY	history of success with R&D (firm's)
RD MKT SHR	expected impact of the R&D project on market share
RD ROR	rate of return for the R&D project
RD SALE CH	expected change in sales attributed to R&D project
SCI TR PRS	availability of scientifically trained personnel
SH T BANK I	short term bank interest rates
STABL MKT	stability of market
STK MKT TR	stock market trends
UNEMPLMT	unemployment

The sample included 15 corporate presidents. Sixty-one percent of the respondents are currently employed in the R & D department of their firms. The general level of formal education is quite high; two thirds of the executives have had at least some post-graduate training.

Half of the executives in the sample work in firms with more than $50 million in sales. The sample was equally split in terms of Canadian or external control, and so correctly represents the state of ownership in Canadian manufacturing.

For an indication of the perceived role of the firm, respondents were asked to rate on a seven point Likert scale market type (stable/volatile), innovation (follower/innovator) and importance of R & D (no involvement/extremely important). Approximately 50% of the executives considered their market stable while 12% considered their market extremely volatile. Few perceived their firm as a follower. R & D involvement was rated as an extremely important activity by only about 16% of the respondents.

Confirming the a-priori dimensions of the information basket and questionnaire item appropriateness.

Factor analysis was used to confirm whether the a-priori dimensions correspond to empirical patterning of variables.

Both general theory and observation of the scree line indicated that six to eight factors could be reasonably extracted. Factor analysis was run, therefore, with varimax rotation being constrained to respectively six, seven and eight factors. Analysis of this factor range indicated that seven factors yielded the optimal granularity level. Results of the varimax rotation indicated that some of the items had high loadings on a number of factors defining correlated factors. Hence, direct oblimin was performed for a somewhat correlated factor space (delta = -0.5). The resulting factors were: (1) general economic conditions, (2) profitability and sales, (3) government support for R & D, (4) project evaluation, (5) information, (6) taxes, and (7) inducements for R & D.

Table 3 presents the significant factor loadings with items ordered according to their a-priori theoretical clusters. The relative weights for each factor were calculated as $\sum_i l_{ij}^2 / \sum\sum_{ij} l_{ij}^2$ where l_{ij} is the factor pattern loading of item i on variable j for the variables loading significantly on each factor. They are presented in the bottom line of the table.

INSERT TABLE 3

Analysis of inter-factor correlations revealed the following associations: The tax dimension correlates positively with general economic trends and more weakly with government support for R & D. Profitability and sales correlates positively with project evaluation (both dimensions include R & D project evaluation items). Information correlates negatively with both the profitability and inducement factors. Government support and information are also somewhat positively correlated. While government support and taxes are somewhat negatively correlated.

The final communality estimates indicate the proportion of the variance of each item that is explained by the factor space. The ordered communality estimates are presented in Table 4. The factor space explains about 60% of the variation of the items.

A few items load significantly on two factors but analysis reveals that such duality is theoretically warranted. For example the item general trends in growth, loaded on both the

Table 3

Factor Analysis Results

	General Economic Conditions	Profitability and Sales	Government Support	Project Evaluation	Information	Taxes	Inducements
I. ECONOMY, GENERAL							
A. Trends							
AV PR ECON	.44						
SH T BANK I	.51						
STK MKT TR	.61						
INVENT TR	.32						
GEN TRD GR	.42	.47					
UNEMPLMT	.57 –						
B. Future Expectations							
EXP GNP GR	.48						
POP GR	.46						
C. Cost Changes (Inducements)							
EX W SETTL	.51						
FOR EXCH R	.44						
EXP INFL	.46					.44	
EXP PRD CH							.48
EXP E REQ							.56
II. ECONOMY, GOVERNMENT ROLE							
A. Costs Direct							
GOVT SUBS			–.62				
L I GOVT L			–.38				
P GOVT CON			–.72				
FAV TX POL			–.39			.60	
B. Indirect							
AC DEPR RD						.79	
ACCL DEPR						.72	
I I GOVT B	.54						
C. Market Influence							
GOV EXP GR	.40		–.45				
FAV TARIF							.33
POLL CONT							.53
D. Information & Support							
GOV SUP MK			–.66				
FEAS STUD			–.80				
GOVT SURV					–.73		
GOV INF CH					–.60		
III. OTHER INFORMATION							
PRIV SURV					–.70		
IV. MARKET							
AV PR GRP							
STABL MKT		.35					
BAR TO ENT				.40			
V. FIRM							
A. Demand							
REC SLS GR		.47					
EXP SLS GR		.73					
LIFE CYCL		.47					
B. Supply, Factors							
SCI TR PRS							
C. Liquidity							
AV PR FIRM		.59					
D. Innovativeness							
RD HISTRY		.30					
VI. PROJECT							
A. Commitment							
COST SLS				.56			
EXP PAY B				.87			
B. Profitability							
RD ROR				.67			
RD MKT SHR		.59					
RD SALE CH		.59					
C. Risk							
P TECH SUC		.36					
PATENTS		.32		.33			
RELATIVE WEIGHTS	.22	.20	.18	.13	.10	.11	.07

factor representing the dimension of general economic conditions and the factor representing the profitability and sales dimension. Expected inflation (loading on factors 1 and 6) affects the formation of general economic expectations and appears as a tax or reduction of real profits. Favorable tax policies (loading on factors 3 and 6) appears as a tool of government support for R & D and as a reduction in tax. Expected growth of government expenditures (loading on factors 1 and 3) affects formation of expectations and appears as government support for R & D apparently reflecting the assumption that growth of government expenditures means more contracts and grants for R & D and market support.

INSERT TABLE 4

Two items are not significant in the factor space: average profit of the industry group and availability of scientifically trained personnel.

The factor analysis confirmed to a large extent the hypothesized decision dimensions (see Table 1). Government items separate into five groups clustering with other items depending on function. Interest on government bonds and growth of government expenditures cluster with the general economic items to form factor 1, general economic conditions. Government surveys and government information cluster with private surveys to form factor 5, information.

Tax related items cluster with inflation to form factor 6, taxes. Pollution control and favorable tariffs cluster with expected productivity change and energy requirements to form factor 7, inducements to R & D. The remaining government items form factor 3, government support of R & D.

The market characteristics and project characteristics also

Table 4: Final Communality Estimates

FEAS STUD	0.79	AV PR FIRM	0.48
AC DEPR RD	0.74	COST SLS	0.48
EXP PAY B	0.73	P GOVT CON	0.48
GOVT SURV	0.72	GOV EXP GR	0.46
FAV TX POL	0.70	REC SLS GR	0.45
EXP SLS GR	0.67	FAV TARIF	0.44
GOV SUP MK	0.65	RD MKT SHR	0.43
GOVT SUBS	0.61	EXP E REQ	0.43
STK MKT TR	0.61	LIFE CYCL	0.43
EXPINFL	0.60	POP GR	0.42
		GEN TRD GR	0.41

GOV INF CH	0.58	EXP PRD CH	0.37
SH T BANK I	0.57	L I GOVT L	0.37
BAR TO ENT	0.57	PATENTS	0.36
BAR TO ENT	0.57	AV PR GRP	0.35
PRIV SURV	0.57	INVENT TR	0.34
EXP GNP GR	0.55	SCI TR PRS	0.33
ACCL DEPR	0.54	P TECH SUC	0.33
STABL MAKT	0.54	POLL CONT	0.31
I I GOVT B	0.54		
UNEMPLMT	0.53		
AV PR ECON	0.53		
EX W SETTL	0.51	RD HISTRY	0.16
RD SALE CH	0.50		
FOR EXCH R	0.50		
RD ROR	0.50		

split up. Factor 2, sales and profitability, includes firm characteristics and market stability and project related items that reflect change in sales and risk. Barriers to entry (as a risk item) and patentability cluster with project commitment items (relative size and payback) and the rate of return.

RESULTS

General Patterns of Information Preferences

Table 5 presents the average importance ratings of the items. The most important items are those pertaining to the following attribute dimensions: the project, the firm and the market. Most of the high ranking items were project specific (with expected growth of sales for the firm completing the set of important decision cues). The items receiving the lowest ratings included indicators of general economic trends and monetary policies.

Insert Table 5
about here

To examine differences in information preferences and relate them to executive attributes and firm characteristics, discriminant function analysis was employed. Using the levels of each attribute and some combinations of attributes, alternative classifications of subjects were defined. The ratings of the forty-seven information items were used as potential independent variables in the various discriminant functions.

The percent of the respondents correctly classified is a measure of the adequacy of the analysis. Half the groupings yielded accurate predictions for at least 80% of the cases, (see Table 6). The accuracy of the discriminant functions can be compared to two measures: the probability of correct allocation

Table 5: Ranking of Items by Average Importance Ratings

High		**Low**	
RD ROR	5.71	AV PR ECON	2.97
P TECH SUC	5.64	P GOVT CON	2.94
EXP PAY B	5.42	EX W SETTL	2.89
RD SALE CH	5.35	GOV INF CH	2.67
RD MKT SHR	5.05	GOVT SURV	2.56
EXP SLS GR	4.99	L I GOVT L	2.49
COST SLS	4.84	POP GR	2.39
		SH T BANK I	2.32
Above Average		GOV EXP GR	2.08
AV PR FIRM	4.72	FOR EXCH R	2.01
SCI TR PRS	4.53		
BAR TO ENT	4.42	**Very Low**	
GEN TRD GR	4.32	INVENT TR	1.91
PATENTS	4.32	UNEMPLMT	1.77
FAV TX POL	4.32	STK MKT TR	1.72
RD HISTRY	4.23	I I GOVT B	1.39
STABL MKT	4.22	H I GOVT B	1.36
GOVT SUBS	4.17	D I GOVT B	1.27
EXP PRD CH	4.04	L I GOVT B	1.23
LIFE CYCL	4.02		
Average			
REC SLS GR	3.87		
AC DEPR RD	3.83		
POLL CONT	3.54		
PRIV SURV	3.43		
FEAS STUD	3.42		
AV PR GRP	3.39		
ACCL DEPR	3.39		
EXP E REQ	3.33		
GOV SUP MK	3.27		
EXP GNP GR	3.13		
FAV TARIF	3.08		
EXP INFL	3.05		

by chance and the probability of maximum allocation (Morrison, 1969).

The discriminant analysis performed better than the probability of maximum allocation in all cases. On average the discriminant analysis performed 30 percentage points better than the probability of allocation by chance, indicating a high degree of accuracy. (Note that there is some upward bias incorporated due to the problem of classifying cases used in the derivation of the discriminant functions, see Frank et al., 1965).

The canonical correlations for each function are also presented in Table 6.

Insert Table 6
about here

The important discriminating variables for each classification of subjects are presented in Table 7 along with the group centroids. When there are only two groups, the group centroids are separated by at least one standard deviation. Important variables are defined to be those with standardized coefficients of .4 and above. The important variables are helpful in naming the discriminant dimensions. Here the dimensions are defined by the factors associated with the important variables. In the case of two functions, some variables are important for both. Varimax rotation would be a useful tool to yield better separation of the dimensions but this option was not available to us.

Insert Table 7

Determination of the group that gives highest ratings to the items helps in interpreting the group distinctions.

Table 6

Results of Discriminant Analysis in 44 Economic Items

Groupings Variables	Definition of Groups	Percent Correct	Chance Probability	Maximum Probability	Canonical Correlation*
Position	1. Presidents 2. Other Management 3. Staff	94	66	80	.71, .56
Department	1. R & D 2. Others	75	54	65	.55
Age	1. <40 2. ≥40	73	56	67	.52
Education	1. Bachelor's Degree 2. Postgraduate	82	59	71	.56
Location	1. Ontario 2. Quebec	84	58	70	.65
Industry	1. High RD (> 3% value added) 2. Medium RD (1-3% value added) 3. Low RD (<1% value added)	87	47	52	.74, .62
Market	1. Stable (1-3) 2. Volatile (4-7)	79	50	50	.57
Firm	1. Follower (1-5) 2. Leader (6,7)	77	54	64	.54
RD Importance	1. Little involvement (1-4) 2. Important (5-7)	83	56	68	.65
Sales	1. < $1 million 2. $1-50 million 3. > $50 million	71	41	46	.70, .40
Employment	1. < 100 employees 2. 100-1000 employees 3. > 1000 employees	75	36	44	.72, .53
Owned	1. Public, widely held 2. Public, control by few 3. Private	64	35	39	.55, .43
Canadian	1. 100% ownership 2. 50-99% ownership 3. < 50% ownership	81	40	51	.68, .60
Control	1. Yes 2. No	82	50	51	.62

*In order of importance when there is more than one discriminant function.

Discriminant Dimensions, Location of Group Centroids, and Important Discriminating Variables

Grouping Variables	Name(s) of Dimension(s)	Location of Group Centroid		Order of Important Variables and Group Attention			
		Function 1	Function 2	Function 1		Function 2	
Position	1. General Economic Conditions and Information 2. Government Support and Project Evaluation	1. 1.59 2. -.10 3. -1.57	-.81 .26 -1.55	SH T BANK I GOV INF CH INVENT TR FOR EXCH R I I GOVT B EX W SETTL	3,1,2 3,1,2 3,2,1 3,2,1 3,2,1 1,3,2	GOVT SURV BAR TO ENT RD ROR EXP PAY B GOV SUP MK	3,2,1 3,2,1 2,1,3 3,2,1 3,1,2
Department	1. General Economic Conditions, Government Support and Sales	1. .40 2. -.75		GOVT SURV EX W SETTL RD MKT SHR FAV TX POL EXP SLS GR GOV INF CH SH T BANK I	2,1 2,1 1,2 2,1 2,1 1,2 2,1		
Age	1. General Economic Conditions, Tax, and Sales	1. .73 2. -.37		AV PR ECON AV PR FIRM FAV TX POL ACCL DPR UNEMPLMT I I GOVT B.	2,1 1,2 2,1 1,2 2,1 1,2		
Education	1. General Economic Conditions, Sales, Project Evaluation and Information	1. .86 2. -.36		FEAS STUD SHT BANK I COST SLS EXP GNP GR EXP SLS GR	1,2 2,1 2,1 2,1 2,1		
Location	1. General Economic Conditions, Information and Government Support	1. -.43 2. .99		SH T BNK I GOV INF CH INVENT TR GOVT SURV P GOVT CON EX W SETTL	1,2 1,2 2,1 2,1 1,2 2,1		
Industry	1. Information, Taxes, Inducement and Availability of Resources 2. General Economic Conditions, Risk, Government Support, Inducements and Availability of Resources	1. .74 2. -.46 3. -2.29	.32 -.45 2.44	AC DEPR RD GOV INF CH SCI TR PRS POLL CONT	3,2,1 3,2,1 1,2,3 2,1,3	SCI TR PRS* PATENTS* INVENT TR* P GOVT CON* EXP E REQ	1,2,3 3,1,2 1,3,2 2,3,1 2,1,3

*Importance ratings <.4.

CONTINUED

Table 7 (Continued)

Grouping Variables	Name(s) of Dimension(s)	Location of Group Centroid: Function 1	Location of Group Centroid: Function 2	Order of Important Variables and Group Attention: Function 1		Order of Important Variables and Group Attention: Function 2	
Market	1. General Economic Conditions, Government Support and Project Evaluation	1. .57 2. -.57		I I GOVT B FOR EXCH R FAV TX POL FEAS STUD RD ROR INVENT TR EXP PAY B	1,2 2,1 2,1 1,2 1,2 1,2 1,2		
Firm	1. General Economic Conditions, Sales and Government Support	1. -.41 2. .72		P TECH SUC EXP SLS GR GOV SUP MK L I GOVT L EXP GNP GR	2,1 2,1 2,1 1,2 2,1		
RD Importance	1. Government Support and Sales	1. .94 2. -.45		GOV SUP MK RD HISTRY	2,1 2,1		
Sales	1. General Economic Condition and Sales 2. General Economic Conditions, Sales and Government Support	1. -1.51 2. -.35 3. .55	-.81 .41 -.20	SH T BANK I EXP SLS GR I I GOVT B LIFE CYCL	2,1,3 1,2,3 3,2,1 1,2,3	SH T BANK I FOR EXCH R P GOVT CON LIFE CYCL	2,1,3 1,3,2 1,2,3 1,3,2
Employment	1. General Economic Conditions, Inducement, and Sales 2. Tax, Government Support, Sales and Information	1. -1.15 2. -.22 3. .72	.58 -.70 .25	SH T BANK I INVENT TR POLL CONT PDP GR REC SLS GR	1,2,3 3,2,1 3,2,1 3,2,1 1,2,3	PRIV SURV AC DEPR RD FAV TX POL L I GOVT L REC SLS GR P GOVT CON	2,3,1 3,1,2 2,1,3 1,2,3 1,2,3 1,3,2
Owned	1. General Economic Conditions 2. General Economic Conditions, Sales and Inducements	1. -.08 2. -.58 3. .71	-.70 .30 .21	SH T BANK I INVENT TR STK MK TR FOR EXCH R UNEMPLMT	3,1,2 2,1,3 1,3,2 3,1,2 1,3,2	UNEMPLMT FAV TARIF I I GOVT B LIFE CYCL	1,3,2 2,3,1 3,2,1 1,3,2
Canadian	1. General Economic Conditions, Governments Support and Sales 2. General Economic Conditions, Sales, Project Evaluation, Government Support and Tax	1. -.97 2. .32 3. .52	-.09 1.32 -.38	FAV TX POL I I GOVT B COST SLS EXP GNP GR GOV SUP MK	1,3,2 1,3,2 1,3,2 1,3,2 1,3,2	BAR TO ENT FAV TX POL AC DEPR RD EX GNP GR RD HISTRY	1,3,2 1,3,2 3,1,2 1,3,2 3,1,2
Control	1. General Economic Conditions, Government Support and Tax	1. -.63 2. .60		FAV TX POL EX GNP GR SH T BANK I I I GOVT B AC DEPR RD	1,2 2,1 1,2 2,1 1,2		

The discussion of results that follows highlights the relationship of differences in information preferences to: (1) decision makers' attributes, and (2) organizational characteristics and individual attribute interactions.

Executive attributes and differences in information preferences

Generally, a preference for a broader basket of information for R & D project evaluation, was indicated by the following overlapping groups:

(1) the young
(2) the executives with longer time of schooling, and
(3) the executives perceiving their firms as "leader" rather than "follower".

Presidents focused relatively more than other executives upon evaluation of general growth trends and wage settlements, i.e. general expectations of investment climates. Senior managers seemed to focus upon information related to expected returns on specific proposals and availability of government support. Other executives (staff) were less discriminating indicating a broader set of variables as important to R & D decision-making. This result confirms the expectation that top level executives concern themselves with strategic problems, while the next echelon of senior management focuses upon tactical problems.

Analysis of the departmental membership of subjects yields support to the observation that information selection reflects parochial tendencies. R & D managers in comparison to others, focus more upon information about technical change while executives in other departments display higher interests in general market information. The exception to this rule is a higher interest of R & D managers in assessment of the impact of R & D on market share as opposed to general investment climates and contribution to overall company growth.

Executives based in Quebec tend more than Ontario executives to value information concerning inventory trends, government support for market development and expected wage settlements, while the latter pay more attention to conditions of short-term financing and direct government demand for R & D services. These distinctions were judged to be a function of different industrial structures in the two provinces rather than cultural differences as English executives in Quebec did not differ in any significant way from Francophones.

Differences in information preferences and organizational attributes

The analysis of discriminating information preferences among subject classifications by organizational attributes, first focused upon the level of commitment in the firm to R & D. Firms with high R & D commitment displayed a relatively low interest in information about inducements and incentives for R & D. This is perhaps a reflection of the institutionalization of R & D investments as a standard operating procedure in the perceived general market role of these organizations. Low commitment to R & D was associated with higher concern with tax incentives and patentability of developments. Medium R & D involvement was associated with preference for information about derived demands for R & D. For example, the probability of government contracts and expected energy requirements received higher ratings by executives in firms with medium R & D involvement.

Executives in firms with highly stable markets showed higher preferences than other executives for information on general economic trends, reflecting a longer planning horizon. Those in volatile markets tended to have higher preferences for short-term information, such as, foreign exchange rates and existing tax incentives.

Executives in firms which they perceived to be leaders, tend to pay higher attention to general economic conditions than those perceiving their firms to be followers. The latter showed more interest in positive inducements for R & D involvement.

Sales size effects upon information preferences of executives, seemed to confirm Galbraith's claim that large firms are concerned with government bond interest as a measure of general economic conditions. Executives from medium and small firms, in contrast, paid higher attention to bank interest rates which affect their costs.

Discriminant functions derived to predict classification of executives by the employment size of their firms indicated the following preferences: Executives from smaller firms were more attentive to information items concerned with liquidity and direct support for R & D. The distance in group centroids between executives from medium and large firms was less than the distance between either of them and executives from small firms. This may reflect a size threshold phenomena in organizational decision procedures.

Ownership and firm control have several interesting associations with information behavior of executives. Executives from firms which are publically owned and the shares of which are widely held tended to pay more attention than other executives to stock market trends, unemployment levels and product life cycle characteristics. Those from privately owned firms showed higher concern than others with interest rates and foreign exchange rates. These differences may reflect the alternative potential financial sources perceived by these groups for R & D investment funding as well as differences in performance evaluation criteria.

The three groups of executives classified by the degree of Canadian control in their firms were equally distant in the discriminant space. Both dimensions included general economic conditions government support and sales. The second dimension included also project evaluation and tax. The first dimension items were all rated as highly important by group 1 (100% Canadian ownership) followed by group 3 (less than 50% ownership). This dimension separates group 1 from the other groups. The second dimension separates group 2 from groups 1 and 3. Group 3 was most concerned with accelerated depreciation of R & D and R & D history; while group 1 rated higher the remaining items in the second dimension.

Where Canadian ownership was sufficient for control, the executives were concerned with favorable tax policies, short term bank interest and accelerated depreciation of R & D. In firms where control is not held by Canadian interests, executives were concerned with general economic conditions such as expected growth of GNP and the interest on government bonds.

Firm - Executive attribute interactions

To identify possible impacts of interactions of individual and organizational attributes upon information behavior, individual attributes -- position and department, were cross-classified with the firm attributes -- industry, market, firm R & D importance, sales, employment, ownership and Canadian control to identify new groupings of subjects. To keep the number of groups manageable, only two position groups were defined: presidents and other management. The discriminant function always performed better than both the probability of chance allocation and the probability of maximum allocation. The highlights of the analysis will be described for the two major discriminating dimensions of the groupings.

1. Position and Location

Dimension 1 included government bonds, government information, favorable tax policy, inventory trends, and short-term bank interest. Dimension 2 included expected wage settlements, sales change attributed to the R & D project, pollution control measures and unemployment.

Presidents were similar on dimension one which explained 61% of the variation. Presidents of Ontario firms were similar to managers from Quebec firms on dimension two explaining 22% of the variation.

2. Position and Industry

Dimension 1 included government contracts, government support of markets, government feasibility studies, average profit of the firm, foreign exchange rates, pollution control, inventory trends, population growth and short term bank interest. Dimension 2 included accelerated depreciation and government contracts.

Presidents in firms with medium and low R & D commitment and managers in firms of high and medium R & D commitment were similar on dimension one (explaining 35% of the variation). Presidents and managers of medium commitment firms were similar on dimension two (30% of the variation).

3. Position and Market

Dimension 1 included government bonds, government information, pollution control and probability of technical success of the project. Dimension 2 included government bonds, sales change attributed to the R & D project, average profit of the firm, foreign exchange rate, inventory trends, and short term bank interest.

Dimension one separated presidents of volatile markets from other presidents and all the managers (explaining 51% of the variation). On dimension two, presidents and managers in volatile markets were similar.

4. Position and Sales

Dimension 1 included government bonds, inventory trends and short term bank interest. Dimension 2 included general trends in growth, expected wage settlements, expected sales growth, average profit of the industry group, short term bank interest and the relative size of the project.

For the largest firms, position was unimportant. For the smallest firms the presidents and other managers were far apart in the discriminant space. On dimension one management in small and medium sized firms were close. For the medium size firms, the distance between presidents and management was moderate.

5. Position and Canadian Control

Dimension 1 included government bonds, private surveys, expected wage settlements and short term bank interest. Dimension 2 included government information, government support of markets, average profit of the firm, inventory trends, population growth, short term bank interest, and the rate of return of the project.

Managers were similar whether the firm was Canadian controlled or not. However, presidents of each group differed. For Canadian controlled firms, presidents and management were similar on dimension two (explaining 29% of the variation). While in the non-Canadian group, presidents were similar to managers on dimension one (explaining 59% of the variation).

6. Department and Market

Dimension 1 included expected productivity change, change in market share attributed to the R & D project, average profit in the economy, expected wage settlements, patents, favorable tax policies, and average profit of the group. Dimension 2 included accelerated depreciation, change in market share attributed to the R & D project, expected wage settlements, expected and recent sales growth, and rate of return of the R & D project.

On dimension one, R & D managers were similar whether their markets were volatile or stable (explaining 46% of the variation). However on dimension two, R & D managers in stable markets were different from the cluster of all the other groups (explaining 36% of the variation).

7. Department and Employment

Dimension 1 included expected sales growth, pollution control, favorable tax policies, inventory trends, and short term bank interest. Dimension 2 included government loans, general trends in growth, change in market share attributed to the R & D project, average profit of the group, and growth of government expenditures.

Employment size of the firm was more important than department in determiningsimilarity of items attended to R&D and other executives of large firms were similar on both dimensions. On dimension one, a cluster formed consisting of both executive groups in medium size firms, another cluster consisted of executives in small firms (explaining 41% of the variation).

8. Location and Sales

Dimension 1 included accelerated depreciation, government contracts, expected sales growth, and population growth. Dimension 2 includes government information, availability of scientifically trained personnel, change in market share attributed to the R & D project, expected wage settlements and expected sales growth.

Sales size was the basis of clusters on the first dimension rather than location (explaining 38% of the variation). On the second dimension, Ontario firms of all sizes and large Quebec firms formed another similarity group (26% of the variation).

POLICY IMPLICATIONS

The study has identified significant differences in information selection patterns among executives. These were associated to differences in executive and firm attributes.

The study suggests that strategies aimed at improvements in the specific attributes of investment opportunities will be universally attended to. In contrast measures aimed at improvements of specific climate attributes or measures which provide specific inducements for R&D stimulation will have a highly selective impact. "Social marketing" strategies to stimulate R&D must provide a fit in content to prevailing information selection patterns of executives and organizations. Similarity groupings such as those identified by this study, will constitute the appropriate target populations for specific strategic designs. Clearly it is also necessary to ensure that other characteristics of the information diffusion process provide a fit with search and evaluation procedures in firms (e.g. fit in media type, form of messages, etc.) and that barriers to actions are removed. Further studies to provide this information are necessary for improvement in the impact of intervention upon R&D investment.

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Multi-attribute Investment Decisions: A Study of R&D Project Selection

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Introduction

R&D management is a complex process. It involves search of the environment for opportunities, generation of options (projects), sequential evaluation at different levels of the organization, project selection, and implementation. To gain a better understanding of this process it is useful to investigate its various components. Schwartz and Vertinsky [32] have focused upon environmental scanning in the process of R&D project selection; while Souder [35], [36], [37] focused his inquiry upon the organizational problem of achieving a consensus. This paper focuses upon another component of the selection process: the formation of individual preferences among R&D investment opportunities. Special attention is paid to the relationship between the characteristics of the executive such as his position and function, the attributes of his organization and the tradeoffs he is willing to make in forming his judgments.

In a previous study a list of forty-seven indicators reflecting the various aspects of the R&D environment were identified after an extensive literature review. These indicators were rated by executives. The results of that study (Schwartz and Vertinsky [32]) suggest that project-specific attributes constitute the information set on which executives and R&D managers universally focus. In particular five project attributes topped the importance ratings, these were:

(1) cost of the project relative to total R&D budget (COST)

(2) the payback period (PAYB)

(3) the probability of technical and commercial success (PSUC)

(4) market share impact (MKT)

(5) expected rate of return (ROR)

Consequently these attributes were selected to represent R&D projects in this study, with the addition of

(6) availability of government funding for the project (GOVT)

The sixth attribute was added to measure the impact of a strategy often used by governments (e.g. Canada) to encourage R&D. In addition to this empirical justification for selecting these attributes from all the possible characterizations of projects, these attributes have received special attention in the literature.

Cost of the project relative to the total R&D budget of the firm is a measure of resource commitment. Economic theory would suggest that the cost by itself would not be important (a measure of profitability should be considered). However, Mansfield [24, p. 310] found that the probability that a firm would fund a project was negatively correlated with the size of the investment required. Concern with financial commitment is such that, especially for small companies, potentially profitable projects may be abandoned before they have had a real chance to succeed (Cooper, [7, p. 175]). For other references on cost, see Scherer [31], Gerstenfeld [15], Tilles [39], Ansoff and Stewart [2], Mottley and Newton [27], and Allen [1].

The payback period is a measure of the time commitment to a project. Payback period norms reflect the subjective time discount and time horizon of the firm. It is also a risk measure in that the longer the time commitment, the less certain the profitability and other estimates. The payback period for R&D projects is generally required to be shorter than that for investment in plant and equipment. For all manufacturing in the U.S. in 1961, 55% of the projects undertaken had an expected payback of less than 3 years and an additional 34% fell in the 3-5 year range (Mansfield, [24, p. 15]). Gerstenfeld

[15, p. 22] found that the payback period varied with size of firm; the average was 4.26 for large firms and 3.5 for small. The high proportion of industrial R&D devoted to development and applied research is indicative of this required short payback period (Leonard, [22, p. 236]; Bright, [5, p. 6]). A maximum payback period may also appear as a constraint imposed by management, thus it may be the deciding factor in project selection (Kotler, [21, p. 30]). For other references, see Ansoff and Stewart [2], Brooks [6], Tilles [39], Cooper [7], Allen [17] and Hamberg [19].

The probability of technical and commercial success is a measure of risk. It may be useful to modify profitability estimates by an estimate of the probability of success. As the risk increases, the value of the return and the maximum expenditure justified decreases (Disman, [11, p. 88]) except in the case of risk seekers. The bulk of R&D is relatively safe (non-risky) and aimed at small improvements in the state of the art. Mansfield [24, p. 56] found that the a priori estimated probability of technical success for projects undertaken averaged 80%. It seems that firms generally do not initiate a project until major technical uncertainties are eliminated. Gerstenfeld [15, p. 22] found a similarly high average of 71%. As basic research projects are more risky than applied, a risk avoiding firm will fund more applied projects (Nelson, [28, p. 304]). See also Scherer [31], Gerstenfeld [15], Quinn [30], Ansoff and Stewart [2], McGlauchlin [23], Thurston [38], Cooper [7], Tilles [39], Cranston [8], Mottley and Newton [27] and Allen [1].

Market share is often a subsidiary goal of firms. From an economic point of view, it is a reflection of the competitive power of the company and of market security. Mansfield [24, p. 89] noted that increased market share seems to be important to some industries, e.g. petroleum and coal, but not for others. Mottley and Newton [27] propose market gain as an auxiliary variable in a scoring model for project selection. See also Peterson [29].

Expected rate of return (ROR) is a measure of profitability in certain environments. Projects can be ranked by the ROR and selected in descending order until the R&D budget is exhausted. Alternatively a minimum acceptable ROR can be imposed as a constraint. The ROR has the advantage of incorporating both costs and revenues. For references, see Mansfield [24], Disman [11], Quinn [30], Kotler [21], Peterson [29] and Allen [1].

Availability of government funding reduces a firm's commitment to R&D. In Canada, as in the U.S., the government directly supplies approximately 60% of the funds for R&D (Brooks, [6]). Government contracts influence both the type of research and the atmosphere in which research activities are undertaken (Quinn, [30]). Government support for R&D has tended to be concentrated in defense and areas that bring national prestige (e.g., space). This may result in a misallocation of funds (Leonard, [22], Brooks, [6]) by limiting the technical resources available for other pursuits (and increasing their costs). On the other hand, decreases in government funding for R&D have resulted in even greater concern for short term payoff and the undertaking of few risky and basic research projects (Brooks, [6], Foster, [14]).

METHODOLOGY

To identify latent structures of decision processes statistical modeling methods are employed. In this approach, from repeated investment decisions (in experimental or real settings), models are estimated to functionally relate project selections and the underlying project attributes. Studies using this approach have investigated decision behaviour in diverse areas:

clinical psychology (Goldberg, [16], graduate student admissions (Dawes, [9]), student performance (Einhorn [13]), stock selection (Slovic, [34]), judicial decisions (Kort, [20]), tenure evaluation (Green and Carmone, [18]), and physician decision making (Schwartz et al. [33]). Different rules were postulated to describe the process by which attributes are combined to yield a judgment. The majority of the studies, however, concluded that the linear model provides an excellent representation of decision makers in many situations (Dawes, [9]). Goldberg [16], for example, concludes that if one's purpose is to reproduce the responses of most judges, then a simple linear model will normally permit the reproduction of 90-100% of their reliable judgment variance. As our prime objective is to develop a "black box" model to predict rather than explain the selection process, we focus, in our analysis, mainly on simple linear or quasi-linear models. (For a discussion of black box models in contrast to process-explanations, see Green [17]).

There have been some criticisms of this method when used for prediction of judgments and determination of causal relationships. Green and Carmone [18] pointed out that the process of modeling might be influenced by the rating scale when subjects could supply reliably only ordinal ratings. In addition, if rating data is ordinal, some configural models (e.g. Einhorn's conjunctive model) cannot be differentiated from the data fit of the additive model. This is the case when the configural models in fact constitute order-preserving transformations of the linear model (e.g. in Einhorn's conjunctive model a logarithmic transformation of data is used to produce a linear model). Birnbaum [3], [4] claimed that using correlations of theoretical predictions and data as indicators of "correctness" might mislead. He claimed that such correlations could be higher for incorrect models than for correct ones. He suggested that functional measurement provided a sounder basis for model evaluation by placing scaling in the context of model fitting and by testing deviation from predictions rather than concentrating upon overall goodness of fit.

To cope with some of the difficulties of employing general linear regression analysis to estimate decision models, two alternative frameworks are used. The first route utilizes orthodox regression and imposes a test procedure to screen out models based upon ordinal perceptions of attribute scales. This procedure, first suggested by Dawes and Corrigan [10] and further developed by Einhorn and Hogarth [13], calls for a repetition of the regression analysis with equal weights. If R^2 values obtained by means of unequal weights are meaningfully higher than R^2 values based on equal weights, then trade-offs can be imputed from the regression coefficients. Otherwise, no trade-off inferences are possible on this basis. The second modeling route permits more flexibility with respect to scaling requirements of the dependent variable. This route employs discriminant analysis to identify those attributes (and their corresponding weights) which explain differences between groups of projects (those which are likely to be funded and those which are not). In this method the objective is to predict group membership on the basis of linear indices combining project attributes and group assignment rules based upon these indices. The indices (discriminant functions) and the assignment rules are estimated by a stepwise procedure which selects attributes so as to maximize functional value differences between the *a priori* groupings.

The employment of these two competing modeling alternatives will permit a further test of validity, the test of robustness.

The Experiment

Subjects were presented with a hypothetical economic environment in which they were instructed to make R&D investment decisions. The projects were described by six attributes: relative cost, payback, probability of success, percent increase in market share, rate of return and percent government funding. Subjects were requested to indicate the probability that they would recommend funding of each project.

The subjects were then presented with sixty project profiles. For the first ten profiles the attributes were presented in random order to avoid attribute ordering effects. For the remaining profiles the attribute order was standardized.

The Sample

A Canadian sample was randomly selected from the population of R&D establishments (Ministry of State for Science and Technology [25]) plus the remainder of the 'Top 100' firms (Morgan [26]) not included in the R&D directory. A second mailing was sent with replacements for those firms declining to participate as well as reminders to those firms which did not respond initially. The questionnaire was sent to the R&D director or to the president of the firm. Ninety-three completed questionnaires were returned (about 30% response rate). The response distribution corresponded well with the population distribution of R&D involvement, indicating that the sectoral breakdown in the sample is representative of R&D establishment frequencies in the population.

The questionnaire asked for supplemental information relating to the attributes of the executive and his firm. Twenty percent of the sample are top management of which half are presidents; sixty percent are currently employed in the R&D department of their firms, while the others are distributed almost equally among production, marketing, and finance departments. The general level of formal education is quite high: more than 50% of the executives have had at least some post-graduate training.

The characteristics of the firms are classified into two major information dimensions: statistical traits (e.g. size) and role perception (e.g. leadership). Half of the organizations represented in the sample have sales over $50 million; seventy percent of the firms represented in the sample are either privately owned or controlled by a few interests. The sample is almost equally split in terms of Canadian control and represents well the state of ownership in Canadian manufacturing. Approximately 50% of the subjects considered their markets somewhat stable and 12% considered their market extremely volatile. Ten percent considered their firm followers, while 35% were leaders. R&D involvement was extremely important for 40% of the firms.

THE RESULTS

Regression Models of Individual Decision Makers

Stepwise linear regression analysis was performed to estimate the decision model for each executive. Table 1 presents the coefficients of the significant attributes. Eighty-three percent of the regressions had R^2 greater than .80. The Einhorn test was performed and the original regression equations provided a better fit in all cases (see Table 1). This suggests that meaningful inferences about trade-off patterns can be derived from the regression weights.

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Insert Table 1 about here

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The attributes in order of frequency of significance are: probability of success (significant for 90% of the executives), payback (77%), rate of return (67%), cost (46%), impact on market share (42%), and government funding (24%). Thus the dimension consisting of success probability, time commitments and profitability assumed a prominent role in the selection process. This result is consistent with ratings of importance reported in a previous study of the economic and environmental factors in R&D decision making (Schwartz and Vertinsky [32]).

For the most part, the sign of the coefficients corresponded to those indicated by theory: cost and payback negative and the rest positive.

It is interesting to note that the results provide additional support to Souder's observation [35], [36], [37] that organizational consensus on criteria often does not exist. Examining, in Table 1, subjects from the same company (i.e. subjects having the same identity number but distinguished by a different letter suffix), one can note that in all cases except one, marked differences in tradeoffs exist among executives from the same company.

The Group Regression Model

A regression model was run using as the dependent variables the average probability ratings of all subjects for funding each of the projects. The results are presented at the bottom of Table 1. To compare the relative importance of the attributes, normalized regression coefficients (scale free) are also given. All the attributes appear as significant in the group model. The order of significance of the attributes is: probability of success (.79),

Table 1

Regression Coefficients for Significant Variables

Executive I.D. #	COST	PAYB	PSUC	MKT	ROR	GOVT	R^2	R_E^2
1	-.24	-.10			1.27		.84	.37
3	-.50	-.27	.76		.35		.83	.39
5		-.44	.45	.44			.61	.31
6	-.48	-.61	1.05	.59			.82	.50
12		-.10	.65	.27		.22	.97	.51
13	-.62		.47		1.10		.83	.33
14	-.56	-.42	.70	.63			.81	.40
19		-.23	.48		.49		.77	.23
20		-.18	.23	.51		.42	.83	.19
26	-.74		.65				.79	.34
42	-.54		.50	1.18			.83	.24
45					1.20		.66	.37
47					1.49		.90	.31
49	-1.55	.26	.72	.31	.57		.88	.14
68		-.24	.46		1.32		.89	.57
74A			.15		1.00		.84	.29
85		-.22	.98	.19			.96	.35
90		-.53	.73			.42	.89	.47
90B	-.49	-.51	.86		.61	.24	.92	.76
90G	-.50	-.36	.75		.45		.83	.52
93		-.57	.60		.96		.88	.39
93A		-.58	.62		.96		.89	.43
94	-.31	-.23	.29		1.27		.93	.49
94B	-.46	-.47	.52	.59	1.27		.89	.53
94C	-.46	-.25	.37	1.14	.34	.18	.93	.46
94D	-.45	-.16	.54	.31	.41		.86	.35
97A				-.43		1.13	.89	.28
101			.21			.33	.84	.20
102		-.26	.29	.76			.82	.17
105		-.19	.69	1.26			.93	.29
115	-.70		.31		1.22		.74	.41
120	-.26	-.25	.78		.90		.96	.55
121	-1.08		.92	.58		.14	.95	.36
127		-.77	.72		.74		.74	.25
129		-.48	.44		1.29		.88	.41
136		-.42	.48	.35		.29	.90	.51
150		-.43	.58		.94		.94	.57
152	-.23		.86	.29			.98	.34
154		-.40	.42		.72		.79	.28
179		-.06	.49	.15	.83		.99	.60
182	-.45		.51		1.22		.89	.43
184			.16		.52		.71	.29
186		-.44		.53	1.14	.60	.85	.50

CONTINUED

Table 1. (Continued)

Executive I.D. #	COST	PAYB	PSUC	MKT	ROR	GOVT	R^2	R_E^2
191		-.24	.56		1.32		.88	.42
204				.43		.67	.93	.32
227C		-.83	.89	.60		.41	.88	.62
227D		-.17	.52		.69	.27	.92	.49
231	-.85	-.20	.55	.49			.64	.20
246		-.61	1.12				.87	.29
250	-.93	-.15	.58		.27		.86	.13
253					1.50		.81	.33
253A	-1.01	-.18	.67		.67		.94	.50
253C	-.26	-.20	.39		1.29		.87	.53
253D	-.47	-.25	.49		1.04		.87	.41
255		-.21	.63	.32	1.06		.92	.45
258	-.30	-.52	.92		.51		.92	.50
264		-.76	.87	.49	.43		.87	.41
269	.39	-.30	.34		1.04		.86	.25
271	-.29	-.21	.41	.49			.69	.19
281	-.39		.69				.86	.20
295	-.40	-.17	.53	-.31	.93		.86	.36
299		-.61	.49			.55	.71	.29
325	-.61	-.13	.50			.78	.97	.51
335	-.40	-.18	.26		.48		.47	.36
337					1.07		.63	.40
358		-.43	.40		1.70		.86	.37
367	-.58		.71	.23	.41		.92	.43
378	-.62		.76			.33	.93	.44
382		-.49	.89		.54		.86	.32
389		-.48	.29		1.67		.86	.31
391A	-.31	-.37	.58	.43	1.34		.93	.56
391B		-.15	.61	.32	1.01		.95	.49
399	-.41	-.26	.40		1.86		.92	.51
400		-.28	.79		.68		.94	.46
412		-.62	.66	.45			.69	.29
416		-.20	.65			.41	.93	.43
432			.28		1.54		.81	.14
436		-.79	.31	1.09	.93	.35	.85	.37
442		-.34	.76				.68	.20
456		-.17		.44	2.24		.96	.41
458	-.31	-.13	.56	.27		.24	.90	.29
463		-.23	.68	.75		.24	.93	.37
465	-.46	-.59	.97	.34	.79		.90	.53
473		-.41	.45	.74		.32	.88	.34
488		- 52	.92		.35		.93	.46
490	-.80		.60		.69		.69	.32
495	-.49	-.15	.42	.64	.48		.86	.41

CONTINUED

Table 1 (Continued)

Executive I.D. #	COST	PAYB	PSUC	MKT	ROR	GOVT	R^2	R_E^2
709		-.32	.32		1.20		.87	.55
710	-.43	-.23	.22		1.36		.85	.46
711	-.68	-.37	.52	-.38	1.77		.83	.40
712		-.30	.82		.45		.88	.36
715	-.37	-.42	.41		1.63		.90	.46
720	-.22	-.40	.78	.59	.47	.12	.98	.07
Average Model	-.30	-.29	.54	.22	.63	.14	.93	
(normalized)	(-.19)	(-.37)	(.79)	(.14)	(.42)	(.16)		

Note:

Entries are the marginal contribution of significant project attributes to the probability of funding derived from linear regression equations (at .05 level of significance). R^2 indicates the percent of the variation of the dependent variable (probability of funding) accounted for by the significant attributes for a given subject; R_E^2 indicates the percent of the variation of the dependent variable that would be accounted for by a linear model using equal weights for the attributes (the Einhorn test). The consistently higher values of R^2 indicate that meaningful inferences about tradeoffs can be drawn from the regression weights.

rate of return (.42), payback (-.37), cost (-.19), government funding (.16) and impact on market share (.14).

Discriminant Analysis Models

Discriminant analysis was performed for each executive by grouping profiles into high and low rated categories (probability of funding for group 1 profiles was less than 50%, and for group 2, greater than or equal to 50%). Other groupings were also tried and for some individuals a better classification model was obtained, but on the average the 50-50 breakdown obtained highest accuracy of reclassification. The results, in the form of the standardized coefficients for the significant attributes are presented in Table 2.

Insert Table 2 about here

The classification obtained by discriminant analysis performed better than the probability of allocation by chance for all subjects. In all cases except two, it provided more accurate classification than the allocation to the maximal group.

Probability of success was a significant discriminating variable for 95% of the executives, payback for 72%, rate of return for 70%, market share for 52%, cost for 48%, and government funding for 41%. This order is similar to the one obtained from the regression analysis (market and cost have changed ranks but are of similar importance). Government funding is significant for twice as many executives as indicated by the regression models. As with the regression models, the signs are generally in the theoretically expected direction.

Table 2

Standardized Discriminant Coefficients for Significant Variables

Executive I.D. #	COST	PAYB	PSUC	MKT	ROR	GOVT	PCORR	PMAX	PCH
1			.36		.87		78	75	63
3	-.18	-.41	.64		.18		90	76	63
5	-.17	-.72	.57	.42		.22	92	73	59
6		-.45	.72	.42	.15	.26	88	58	51
12			.90	.23	.25		85	60	52
13	-.32		.18		.90	-.37	85	67	56
14	-.40	-.62	.59	.43		.17	92	77	61
19		-.20	.73		.45	.16	82	67	56
20	.46			.57	-.37	.44	73	63	53
25	-.74		.56			.19	97	83	72
43	-.13	.17	.56	.75	.24		83	50	50
45	-.42	-.33	.49		.56		82	70	58
47			.28	.25	.88		90	58	51
49	-.94		.11		.10	.19	97	53	50
68		-.25	.51	.19	.65	.16	90	63	53
74A			.46		.81		78	62	53
85		-.17	.91	.42			90	70	58
90	-.19	-.25	.45			.42	82	57	51
90B	-.24	-.35	.70	.35		.21	80	58	51
90G		-.35	.82		.30		88	68	56
93		-.55	.29		.64		88	57	51
93A		-.55	.33		.64		90	55	51
94	-.36	-.32	.21		.77		83	58	51
94B	-.28	-.73	.14	.33	.44	.17	82	56	51
94C	-.40	-.28	.22	.88		.16	63	52	50
94D	-.64	-.62	.54				83	77	63
97A			.20	-.15		.93	93	52	50
101	.19	.54	.40		.21	.56	93	80	68
102	-.50	-.69	.20	.52	-.42		97	87	77
105		-.18	.50	.86			88	75	63
115			.75	.30	.68		83	63	53
120		-.27	.68		.44	.26	92	62	53
121	-.63		.49	.48	.16	.17	83	60	52
127		-.77	.39		.35		93	65	55
129		-.45	.37		.69	-.15	87	57	51
136	-.22	-.87	.50			.26	90	80	68
150	-.18	-.64	.42		.48		90	50	50
152	-.23		.92	.29			87	68	56
154		-.75	.33		.43		88	78	66
179	-.15	-.20	.25		.86		93	73	61
182			.67	.11	.57	.17	90	57	51
184			.74		.55		77	77	65
186	-.18	-.65		.24	.44	.56	83	55	51
191			.45		.81		87	67	56

CONTINUED

Table 2 (Continued)

Executive I.D. #	COST	PAYB	PSUC	MKT	ROR	GOVT	PCORR	PMAX	PCH
204	.21			.28		.93	90	57	51
227C		-.84	.48	.32		.23	80	62	50
227D		-.38	.39	.28	.50	.47	80	65	55
231	-.86	-.54	.17	.28			92	87	77
246	-.15	-.75	.67				85	53	50
250	-.95		.22				93	83	72
253			.45	.21	.79		90	58	51
253A	-.73	-.34	.40		.32	.13	92	72	60
253C			.54	.40	.61	.19	92	53	50
253D	-.30	-.21	.43	-.21	.68		87	63	53
255		-.20	.42	.17	.70	.25	90	77	65
258	-.15	-.61	.64		.30		93	50	50
264		-.71	.51	.39	.17		82	57	51
269	.16	-.41	.16		.79		85	53	50
271	-.40	-.32	.61	.63			90	80	68
281		.16	.94			.20	85	58	51
295			.52		.64	.29	82	68	56
299		-.81	.19	.21		.72	85	72	60
325	-.27		.50			.77	93	50	50
335	-.43	-.55	.35		.53		92	90	82
337			.43	.41	.68	.20	87	77	70
358	-.19	-.50	.16		.74		83	55	51
367	-.38	-.14	.66		.39	.21	82	60	52
378	-.29		.71		.17	.43	90	55	51
382		-.66	.74			.22	78	50	50
389	.16	-.38		.15	.84		87	60	52
391A		-.23	.42	.32	.73		90	60	52
391B		-.14	.32	.24	.84		92	73	61
399		-.13	.42		.76	.16	95	60	52
400		-.40	.56	.20	.55		90	68	56
412	-.16	-.80	.41	.23	.24		92	75	63
416			.81			.52	77	57	51
432			.29		.90		78	62	53
436		-.73	.14	.47	.37		87	52	50
442		-.23	.98				75	65	55
456		-.31		.22	.88		93	73	61
458	-.26	-.51	.72	.26		.40	78	60	52
463		-.31	.72	.62		.26	87	72	60
465		-.47	.72	.17	.33		87	57	51

CONTINUED

Table 2 (Continued)

Executive I.D. #	COST	PAYB	PSUC	MKT	ROR	GOVT	PCORR	PMAX	PCH
473		-.74	.33	.60		.39	80	57	51
488		-.79	.61	.11			90	52	50
490	-.21		.67		.57		82	60	52
495	-.62	-.34	.43	.52	.19		85	72	60
703	-.29	-.33	.28	.21	.68	.23	90	53	50
710	-.15	-.24	.29		.82		90	65	55
711	-.24	-.32	.35	.15	.72		92	62	53
712		-.23	.89		.24		83	52	50
715		-.36	.39		.73		93	65	52
720	-.13	-.44	.47	.29	.56	-.20	97	75	63
Average Models									
A		-.43	.62		.49		78	35	24
B		-.38	.64		.48		92	55	53

Note:

Entries under project attribute headings are the coefficients of the linear discriminant functions for each subject (at .05 level of significance). These coefficients have been derived from linear discriminant analysis that maximized the difference between the two groups of projects. Measures of goodness of prediction are provided by the columns PCORR (percent of projects correctly allocated by the discriminant functions), PMAX (percent of projects that would be correctly allocated if all were assigned to the group with the highest *a priori* probability of membership) and PCH (percent of projects that would be expected to be correctly allocated by chance allocation on the basis of *a priori* group membership probabilities).

The Group Discriminant Model

Two group discriminant models were estimated, assigning profiles to groups on the basis of the average scores. Two groupings were tried: model A had five groupings (<20%, 20-39%, 40-59%, 60-79%, and 80-100%) and model B had three groupings (<20%, 40-59%, 80-100%). Both models performed better than allocation by chance and maximum allocation. The significant discriminating variables and their coefficients were similar in both models. Probability of success was most important, followed by the rate of return and payback. The results are reported at the bottom of Table 2.

Comparison of Regression and Discriminant Models

The comparison of discriminant models and the regression models obtained for the same subjects provides additional evidence on the validity and robustness of the relationships. Table 3 presents the ordered significant attributes for both the regression and the discriminant models (for ease of comparison, normalized regression coefficients are used). In twenty-three of the cases the order of attributes is preserved (preservation of order here is defined to include cases where more attributes are present in one model than the other but the order of the attributes is the same and the additional attributes are of the lowest importance). In 68 of the cases there are only minor differences among the models. In only two of the cases are the models quite different.

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Insert Table 3 about here

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There are two cases of counter-consensus direction of impact of the attributes that appear in both the regression and the discriminant models.

Table 3

Comparison of Discriminant Analysis and Regression Analysis

Executive I.D. #	Significant Variables in Descending Order	
	Regression	Discriminant
1	R C PB	R PS
3	PS PB C R	PS PB C=R
5	PS PB M	PB PS M G C
6	PS PB M C	PS PB M G R
12	PS G PB M	PS R M
13	R PS C	R G C PS
14	PS PB M C	PB PS M C G
19	PS R PB	PS R PB G
20	G PS M PB	M C G R
26	PS C	C PS G
43	M PS C	M PS R PB G
45	R	R PS C PB
47	R	R PS M
49	PS C R PB M	C G PS R
68	R PS PB	R PS PB M G
74A	R PS	R PS
85	PS PB M	PS M PB
90	PS PB G	PB PS G C
90B	PS PB R C G	PS PB=M C G
90G	PS PB C R	PS PB R
93	PS PB R	R PB PS
93A	PS PB R	R PB PS
94	R PS PB C	R C PB PS
94B	R PS PB M C	PB R M C G PS
94C	M PS PB C R G	M C PB PS G
94D	PS C R PB=M	C PB PS
97A	G M	G PS M
101	G PS	G PB PS R C
102	M PS PB	PB M C R PS
105	PS M PB	M PS PB
115	R PS C	R PS M
120	PS R PB C	PS R PB G
121	PS C M G	C PS M G R
127	PS PB R	PB PS R
129	R PS PB	R PB PS G
136	PS PB G M	PB PS G C
150	PS R PB	PB R PS C
152	PS M C	PS M C
154	PS PB R	PB R PS
179	PS R M PB	R PS PB C

CONTINUED

Table 3 (Continued)

Executive I.D. #	Significant Variables in Descending Order	
	Regression	Discriminant
182	R PS C	PS R G M
184	R PS	PS R
185	R G PB M	PB G R MC
191	R PS PB	R PS
204	G M	G M C
227C	PS PB G M	PB PS M G
227D	PS R G PB	R G PS PB M
231	PS C M PB	C PB M PS
246	PS PB	PB PS C
250	PS C PB=R	C PS
253	R	R PS M
253A	PS C R PB	C PS PB R G
253C	R PS PB C	R PS M G
253D	PS R PB C	R PS C PB=M
255	PS R PB M	R PS G PB M
258	PS PB R C	PS PB R C
264	PS PB M R	PB PS M R
269	R PS PB C	R PB PS=C
271	PS M PB C	M PS C PB
281	PS C	PS G PB
295	PS R C PB M	R PS G
299	PB PS G	PB G M PS
325	G PS C PB	G PS C
335	PS R C PB	PB R C PS
337	R	R PS M G
358	R PS PB	R PB C PS
367	PS C R M	PS R C G PB
378	PS C G	PS G C R
382	PS PB R	PS PB G
389	R PB PS	R PB C PS
391A	R PS PB M C	R PS M PB
391B	PS R M PB	R PS M PB
399	R PS PB C	R PS G PB
400	PS R PB	PS R PB M
412	PS PB M	PB PS R M C
416	PS G PB	PS G
432	R PS	R PS
436	PB M R PS G	PB M R PS
442	PS PB	PS PB
456	R M PB	R PB M
458	PS G C M PB	PS PB G PS=C

CONTINUED

Table 3 (Continued)

Executive I.D. #	Significant Variables in Descending Order	
	Regression	Discriminant
463	PS M PB G	PS M PB G
465	PS PB R C M	PS PB R M
473	PS PB M G	PB M G PS
488	PS PB R	PB PS M
490	PS C R	PS R C
495	PS M R C PB	C M PS PB R
709	R PS PB	R PB C PS G M
710	R PS PB C	R PS PB C
711	R PS PB C M	R PS PB C M
712	PS PB R	PS R PB
715	R PS PB C	R PS PB
720	PS PB M R C=G	R PS PB M G C
Average Models	PS R PB C G M	PS R PB

Note:

The entries are the significant project attributes in order of contribution. Attributes which do not appear make no significant contribution. (C = COST, PB = PAYB, PS = PSUC, M = MKT, R = ROR, and G = GOVT). Though the two models pose different questions, the degree of attribute order preservation provides evidence of robustness.

In the other cases the sign is correct in one of the two alternative models and/or the attribute is of low significance or does not appear at all in the alternative model. One executive had held preferences to higher costs reflecting perhaps a tendency for empire building. In another case market share had a negative impact upon project funding reflecting perhaps a concern with antitrust legislation.

<u>The Group Models</u>

The order of the three most significant variables is the same in both models indicating that the probability of success, rate of return and payback are the most important attributes for R&D project evaluation and selection.

<u>External Validity</u>

While it is impossible to ascertain external validity as the real decision environment is confounded, several unsolicited comments submitted by the respondents provide some evidence of credibility. Consider a few examples:

a) <u>Executive #93A</u>

<u>Description</u>:

Subject is a manger of the sales department in a chemical firm with sales of $1-10 million, privately owned, not Canadian controlled. Market is somewhat volatile, firm is a leader and R&D is extremely important.

<u>Subject's Comments</u>:

"In the case of my own company R&D is largely financed by sales of existing products so that the influence of government subsidies and changes in the money market do not generally enter into our product (or project) evaluations. We generally look for a rate of return of 30% or more, and a pay-back period of around 3 years. Our impact on the market and the probability of marketing or of technical success is also critical to our evaluation process. This requires a considerable amount of market research and clinical research before a product is launched".

Models:

The models are largely in congruence with these comments. In the discriminant model the attribute order of significance is: rate of return, payback, and probability of success. The attribute order is reversed in the regression model. Market share, however, does not appear in either model. But, impact upon market is captured perhaps by the profit indicator.

b) Executive #97A

Description:

Subject is a manager of the R&D department of an electrical products firm with sales of $50-75 million, publicly owned with control by a few interests, not Canadian controlled. Market is stable, firm is a follower, and R&D is extremely important.

Subject's Comments:

"In reviewing the answers we have provided you might be interested in noting that we are a very conservative Company that is involved in developing and marketing state-of-the-art products. This leads to an interesting dilemma which has been solved through the use of Government funding (mainly Canada and the U.S.A.). Every attempt is made to get any R&D effort fully paid from external sources. Very often we sell our R&D effort outright. This has the advantage of achieving 100% funding but the disadvantage that we do not have exclusive rights to the resulting product. We rely on our initial experience with the resulting product as a means of remaining competitive in any potential production requirement."

Models:

Government funding is most significant in both the regression and discriminant models. Market share is also important (negative) in both, while the discriminant model includes probability of success.

c) Executive #121

Description:

Subject is a manager of an R&D department in a firm in the transportation and communications sector with sales greater than $250 million, publicly owned, Canadian controlled. Market is extremely stable, firm is a follower, and R&D is of moderate importance.

Subject's Comments:

"We evaluated the sixty itemized conditions to indicate probability of funding by allocating points as follows to arrive at a ranking order.'

		Points
Probability of success	50%	0
	50 to 60%	1
	60 to 70%	2
	70 to 80%	3
	80 to 100%	4

R&D cost as related to total R&D expenditure	>30%	0
	<30%	3
Percent Market	<10%	0
	>10%	2
Percent Government support	<10%	0
	>10%	1

We consider that the above four criteria are the most important ones in our decision making. Probability of success is the highest criteria commanding the maximum points (4) for probability of success between 80 to 100%.

After establishing the ranking order we arbitrarily divided the sixty situations into ten parts giving 100% probability of funding to the top six in the ranking order and working our way down the ladder."

Summary of the model provided: probability of success and cost are most important, followed by impact on market share and government funding.

Models:

The models are confirmed by the comments. In the regression model the order of the attributes is probability of success, cost, impact on market share and government funding. The discriminant model reverses the order of the first two variables.

d) Executive #253

Description:

Subject is a manager of an R&D department of a firm in the petroleum and coal sector, not Canadian controlled.

Subject's Comments:

"Your questionnaire ... appears to assume that some level of government subsidy is necessary to make the private sector function. My own personal conviction is that such payments either have no effect or distort the market system by encouraging industry to embark on uneconomic, unsustainable projects. I believe the main problem facing industrial innovators in Canada today is to define economically viable projects in an environment of rapid inflation, price controls, increasing and variable government regulations and very heavy taxation."

Models:

For the regression, the only significant attribute is the rate of return. For the discriminant model, the important attributes are rate of return, probability of success and impact on market share. The models are supported by the comments: government funding is not important and profitability measures are.

e) Executive #711

Description:

Subject is a Vice President of a chemicals firm with sales of $750-100 million. Market volatile, firm neither a follower nor a leader, R&D of moderate to low importance.

Subject's Comments:

A model of the procedure used by the firm was provided. The model selects projects to maximize expected rate of return adjusted for resource and time commitment by calculating a discounted cost function as a combination of the payback and the relative cost of the project.

Models:

In both the regression and discriminant models, the order of significant attributes was: rate of return, probability of success, payback, cost and impact on market share. The models are generally confirmed by the comments with the addition of impact on market share (low coefficient, .15).

Analysis of Winning Sets

This section deals with project attribute levels associated with high probabilities of funding. We thus focus on those projects which received, on the average, a funding probability of 70% or more in our sample, defining them as winning sets (see Table 4). After characterizing the

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Insert Table 4 about here

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winning set of projects for the total sample, we focus on differences among winning sets for groups of subjects classified on the basis of alternative personal and organizational attributes. One must note, however, that the high degree of fit obtained in the estimated group models of judgment indicates that differences among individuals are relatively low, and therefore one may expect similarity of judgment patterns among groups. The interpretation of intergroup differences in judgment patterns will focus only on those patterns where differences are significant.

Generally, the rate of return for successful candidate profiles is high, (greater than 35%), payback is less than 5 years, impact on market share is greater than 15% increase, and government funding greater than 34%.

Table 4

The Winning Set of Projects and Additions and Deletions by Executive Groups

	ATTRIBUTES						EXECUTIVE GROUPINGS																																		
	COST	PAYB[1]	PSUC	MKT	ROR	GOVT	POSITION			MARKET		SALES SIZE			EMPLOYMENT			OWNERSHIP			NON-R&D MANAGERS		AGE		EDUCATION		R&D/V.A.			DEPT. & LOCATION				DEPARTMENT & MARKET				DEPARTMENT & FIRM			
							1	2	3	1	2	1	2	3	1	2	3	1	2	3	1	2	1	2	1	2	1	2	3	1	2	3	4	1	2	3	4	1	2	3	4
WINNING SET	50%	2-4	90%	24%	49%	75%																							D												
	45%	2-7	93%	20%	50%	71%																																			
	2%	0-9	74%	37%	35%	34%									D														D												
	2%	4-7	92%	29%	36%	60%	D																																		
	1%	5-0	95%	20%	42%	64%	D								D																										
	26%	4-5	83%	49%	37%	88%	D				D		D		D				D		D			D					D		D				D		D		D	D	
	23%	1-9	74%	15%	47%	86%	D						D		D						D			D											D	D				D	
ADDITIONAL PROJECTS	11%	2-4	57%	26%	34%	52%			A																				A												
	31%	2-11	86%	6%	36%	34%			A																																
	13%	1-7	62%	38%	43%	21%			A			A							A			A							A				A								
	14%	2-7	73%	44%	30%	32%			A	A				A					A			A			A				A	A			A	A				A			A
	14%	1-11	72%	22%	36%	10%			A							A			A			A																			
	10%	5-9	68%	34%	42%	92%			A																											A					
	15%	0-6	86%	3%	23%	41%								A																											
	50%	0-9	82%	26%	30%	17%										A										A				A											
	33%	3-9	82%	5%	48%	75%																							A												

NOTES: [1]PAYB measured in yrs-months D = deletions A = additions

The WINNING SET is the group of projects with an average probability of funding of at least 70% for all executives. The ADDITIONAL PROJECTS are those receiving at least 70% for the indicated groups of executives. The following are the executive groupings:

<u>POSITION</u> (1 = president, 2 = senior managers, 3 = staff). <u>MARKET</u> (1 = stable, 2 = volatile). <u>SALES SIZE</u> (1 = <$1 million, 2 = $1-50 million, 3 = >$50 million). <u>EMPLOYMENT</u> (1 = <100 employees, 2 = 100-1000, 3 = >1000). <u>OWNERSHIP</u> (1 = public, widely held, 2 = public, control by few, 3 = private). <u>NON-R&D MANAGERS</u> (1 = Canadian control, 2 = non-Canadian control). <u>AGE</u> (1 = <40, 2 = ≥ 40). <u>EDUCATION</u> (1 = B.A., 2 = Post-Graduate). <u>R&D/V.A.</u> (1 = ≥ 3% value added, 2 = 1-3%, 3 = <1%). <u>DEPT. & LOCATION</u> (1 = R&D, Ontario, 2 = R&D, Quebec, 3 = other, Ontario, 4 = other, Quebec). <u>DEPT. & MKT</u> (1 = R&D, stable, 2 = R&D, volatile, 3 = other, stable, 4 = other, volatile). <u>DEPT. & FIRM</u> (1 = R&D, follower, 2 = R&D, leader, 3 = other, follower, 4 = other, leader).

Cost levels did not display a consistent pattern. Cost levels vary over the total range. Probability of success is greater than 74%. The tradeoffs are striking for these profiles: if the payback is less than 2 years, a probability of success of 74% is acceptable; if the payback is moderate (about 2½ years) the compensating probability of success must be high (about 90%); the same holds for long paybacks (4½ to 5 years) with one exception, a project where a lower probability of success (83%) was compensated by high market impact and high government funding. Other projects in the portfolio with ROR greater than 30%, generally had low probability of success or long paybacks.

Analysis of differences in winning sets (additions or deletions from the total sample set) identified the following relationships between project attribute tradeoffs and individual organizational characteristics:

Presidents deleted from the winning sets all projects with payback period higher than 2½ years and all projects with high (>80%) government funding. Senior managers seemed to favor the winning set identified for the sample as a whole, while staff executives were making more liberal tradeoffs between rates of return and risks, expanding the winning set with two riskier investment alternatives.

Executives in stable markets differed from those in volatile markets in the trade-offs they made between probability of success and longevity of payback period. Those in volatile markets eliminated from their winning set projects with long payback periods, except for those with markedly high probability of success.

Large companies (with sales above $50 million) tended to make more liberal tradeoffs between rates of return and payback periods and between risk and rates of return. To the winning set they added projects with moderate rates of return and shorter payback periods as well as projects with higher risks and higher rates of return. Small companies (with less than $1 million in sales) tended to accept high risks for high rates of return only if cost commitments are low and expected impact upon market share is high.

Size measured by employment is positively related to the range of risk trade-offs. Small companies (having below 100 employees) tended to focus on safe projects only with high ROR (>36%), high probability of success (>90%) and short payback period (>5 years). Medium companies added to the winning set safe projects with high expected rates of return but with longer payback horizons. Large companies (with above 1000 employees) permitted the whole range of tradeoffs identified in our discussion of the average winning set for the total sample.

The impact of ownership patterns on funding preferences suggests that public companies with widely held shares have greater concern with market share for which they are willing to take higher risks. Concentrated ownership patterns (both in private and public corporations) are not associated with any such attention to market share performance.

No differences were discovered among winning sets of Canadian and non-Canadian controlled companies. However, when R&D project managers are removed from the sample, and comparisons are made between the winning sets of executives in Canadian and non-Canadian controlled firms, it is noted that Canadian executives tend to choose conservatively, imposing higher safety margins upon project selection.

POLICY IMPLICATIONS AND CONCLUSIONS

The study has several implications for government policy with respect to R&D stimulation in the private sector. First, it suggests the usefulness of general compensatory models for predicting preferences among R&D investment opportunities. While we have demonstrated in another study the selective impacts of environmental economic variables upon R&D investment, a high consensus was demonstrated in this study in executive judgments of projects by their specific attributes. This consensus was reflected in the high correspondences between predicted values and observations for the models representing the sample as a whole, as well as the similarity of winning sets of alternative executive and firm groupings.

Differences in judgment formation are realized mainly in ranges of tradeoffs between risks and rates of return. Government subsidies and participation in funding in the private sector do not have a high direct impact upon R&D decisions. On the basis of comments received from a variety of executives there is fear of increased level of government interference in managerial decisions associated with receipt of government funds. This observation, in view of the tight upper bounds most companies impose upon acceptable risk levels, points to a new role for government. The role we propose is that of an independent insurance agency. Insurance permits firms to trade rates of return and risks. This provides an expanded choice space and many candidate projects rejected now as too risky (though with high expected payoffs) may join the winning sets.

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R&D Project Evaluation: from firm behavior to normative models to implementation

A State of the Art Review*

by

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Introduction

R&D activities - innovation, new product development, process improvements to reduce costs and product improvements to extend the life or market of a product - are the tools by which a modern company competes (Levitt, 1966). The economic health of a company depends on how well it keeps pace with technological change. R&D is also claimed to be an activity which can provide a solution to the problem of stagnation in the industrial nations. Yet R&D management is fraught with uncertainties and risks. The success of research activities depends on the economic environment. Research programmes can quickly be made obsolete by events external to the firm. Technological advances by competitors often require adaptive planning, making current plans unprofitable. The risks involved in such activities are assumed to restrict commitments by the private sector to levels which are lower than socially desired, especially when a conservative posture is adopted by firms as a response to declining economic environments. It is, therefore, the policy for many governments to seek direct and indirect means to stimulate R&D expenditures. For example, the Canadian federal government has been providing financial assistance for R&D since 1961. (In 1973 alone this commitment amounted to $100 million.) There are many pressures to increase such commitments, especially in countries whose competitive international position has been reduced significantly due to rising costs and the entry of new producers. Yet many doubts prevail as to whether such commitments in fact stimulate, or just replace, private R&D investment. Improved results can only come from better management of the entire R&D effort.

In this paper, we attempt to describe the "state of art" in (1) explaining R&D investment behavior, (2) normative models for R&D decision making, (3) studies of barriers to implementation of proposed R&D decision models and (4) investigation of existing internal R&D investment decision procedures (standard operating procedures).

Determinants of R&D investment behavior

R&D is an activity aimed at reducing uncertainty about the environment inherent in new product/new process ventures. It is an activity that produces and applies knowledge. R&D management can be analyzed in the general decision making framework. R&D is an activity undertaken in response to perceived gaps in the fulfillment of corporate objectives. Thus, perception of this gap and recognition of need are the first prerequisites. The next essential element is the perception of control and the recognition of opportunities for transforming the environment. This requires both availability of resources and generation of alternative projects. The next requirements for successful R&D management are evaluation and selection procedures.

The literature on determinants of R&D investment provides a variety of complimentary foci of explanation. These may center upon different elements inhibiting or stimulating R&D investment by affecting objectives, constraints or benefit calculations. Schumpeter (1971, p.37) noted an apparent clustering of innovations during economic booms. Prosperity helps induce innovation by increasing the expected returns. Size of the general market is also important in determining industrial research patterns (Quinn,1966, p.14). Thus population growth by increasing the market would be expected to have some influence on R&D decisions. Bright (1970, p.67) labels population trends a prime, but often neglected, signal for the 10-30 year planning horizon. He points out that the Paley report on materials needs for 1975 published in 1952 was based on faulty population forecasts which led to under-estimates of demand. Keynes (1964, p.151) pointed to the role of stock market trends in the formation of long-term expectations and, therefore, to their role in investment and innovation. Keynesian analysis would also point to the influence of interest rates, while Galbraith (1973) would argue that profit and internal savings are more important, as the firms in what he defines as the planning sector are unlikely to borrow funds.

Much of R&D is induced by the changing structure of resource costs, thus expected wage settlements, productivity change, inflation, and energy requirements are possibly relevant to R&D decisions. (See Smookler, 1966, Rosenberg, 1974, Kamien and Schwartz, 1968, Fellner, 1971 and Hamien and Ruttan, 1974.)

The exchange rate plays a dual role depending on the company. It may be an indicator of expected cost changes or an indicator of demand changes. Leonard (1971, p.234) reported studies that found a positive correlation between export performance and R&D effort in U.S. industries.

The role of government as it influences R&D covers several areas: direct influence on costs, indirect influence on costs via the availability of funds, supply of information, and influence in the marketplace. The risky nature of research activity results in a free enterprise economy underinvesting in R&D, especially in basic research (Arrow, 1962). Also, public support for R&D is needed when returns accrue to more than the individual firm. When social benefits outweigh private benefits through diffusion of gains, some government support may be necessary to ensure proper allocation of R&D effort. Thus government subsidies, grants, and loans are made to encourage R&D. Government aid to reduce the cost and risk of R&D and thus increase the benefits may be of much importance. Favorable tax policies imply a cost sharing, also reducing an individual firm's commitment to R&D. In Canada, as in the U.S., the government directly supplies approximately 60% of the funds for R&D (Brooks, 1972). Government contracts influence both the type of research and the atmosphere in which research activities are undertaken (Quinn, 1967). Government support for R&D has tended to be concentrated in defense and areas that bring national prestige (e.g. space). This may result in a misallocation of funds (Leonard, 1971, Brooks, 1972) by limiting the technical resources available for other pursuits (and increasing their costs). On the other hand, decreases in government funding for R&D have resulted in even greater concern for short-term payoff resulting in the undertaking of few risky and basic research projects. (Brooks, 1972, Foster, 1971).

Government also indirectly influences costs by influencing the market interest rate and expectations of future profitability as reflected in the interest rate. Accelerated depreciation increases internal funds available. Government support of feasibility studies and market development are also means of reducing costs -- specifically reducing the external, social costs of product innovation.

The market influence of the government includes the role of the growth and size of government expenditures. This is reflected in many ways including formation of expectations about the economy, inflation, growth of demand and cost of funds. Tariff policy influences demand expectations.

The government role in the social assessment of R&D and the evaluation and control of technology is important in directly influencing areas of innovation. Pollution control and environmental protection regulations have influenced innovative processes for handling waste materials. As noted by Bright (1970, p.63) "Social, political and now ...ecological changes may alter the speed and direction of the innovative process." Technological forecasting must be concerned with social forces such as special interest groups and government regulations that will influence technology and the acceptance of change (Thurston, 1971).

Information gathering and processing capabilities are crucial to R&D decisions. In technologically oriented firms the time spent on information gathering is staggering: "In a typical research laboratory scientists spend 80% of their time trying to look things up and less than 20% doing what they are paid for" (Drucker, 1975).

Market structure apparently plays a key role in industrial R&D but there is much disagreement about the precise patterning of effects. Competiton, concentration and entry barriers may be important for R&D decision making. Research spending can be viewed as a means of creating product differentiation. Cooper (1966, p.176) reports that some companies purposely develop products for small markets believing that there will thus be little incentive for competitors to challenge them. R&D would be low in areas where the prospects for differentiation are low and also where marked differentiation already exists (Comanor, 1967, p.652). One would expect that competition would stimulate firms to innovate in order to acquire competitive advantage or to remain competitive. Competition would be expected to facilitate fast imitation of technological innovation for the same reasons. However, Mansfield (1969, p.17) found that innovations spread less rapidly in concentrated industries. Scherer (1971, p.370) observed greater R&D in industries where the minimum plant size represents 4-7% of the market share and the required investment is $20-70 million. Beyond these ranges, there appear to be no advantages to entry barriers. In contrast, Schumpeter (1971) has argued that monopolistic or oligopolistic industries innovated more rapidly because the threat of entry of new firms causes them to behave as competitors. This view is supported by others (Williamson, 1964, p.67).

Stability of market, reflecting both the age of industry and nearness to the science/technology frontier, has been proposed as an important factor in explaining R&D investment behavior. A firm near the science/technology frontier must be alert to possible innovations by competitors and must participate actively in R&D to maintain its market position. When the industry is far from the boundary (a mature industry), technological progress is evolutionary though breakthroughs in other industries may make the entire market obsolete (Ansoff and Stewart, 1967).

Sales characteristics (both dynamic and static) play an important role in determining the importance of technology to the firm. Growing sales might be expected to make a firm more responsive to technological change and lead to increased research intensity; however Leonard (1971,p.254) found that the causality ran the other way. Lithwick (1969, p.5) observed that the evidence revealed a negative relationship between R&D intensity and growth. Increasing R&D is an offensive strategy to combat stagnation.

Product life cycle considerations have been incorporated in strategic models for R&D (Quinn, 1967, Kotler, 1967, Tilles, 1966). Ansoff and Stewart (1967, p.76) stress the importance of life cycle for product innovation. Short cycle products require constant and continual product innovation, quick response and concurrent planning by marketing and engineering divisions. Decisions must be based on approximate and incomplete data rather than precise details. Long cycle products can enjoy sequential planning with detailed R&D preceding manufacturing and marketing planning.

Ready availability of scientific personnel may be crucial to the decision to undertake a project. In the early sixties in the U.S., the growth of aerospace and defense projects placed a burden on other R&D programmes. The demand for scientific personnel in these areas increased the cost of other programmes resulting in a slackened pace of civilian research. The slow down was especially significant in low technology, mature industries where R&D spending is sensitive to economic cost factors (Brooks, 1972, p.115). Ansoff and Stewart (1967,p.79) make the point that for successful innovation it is not necessary, and often not desirable, to have a high ratio of scientific to total staff.

Availability of funds affects the feasibility of R&D investment. Williamson (1965,p.67) contends that the advantages in financing experienced by large firms enhance innovative performance. Yet, affluence may lead to complacency. Cyert and March (1963) postulate that innovation is induced by market stress and pressure on profits. An increase in profits relative to the industry rate appears to decrease R&D activity.The'poor' innovate.However,the empirical evidence is not conclusive. Scherer (1971,p.364) found that the direction of causality goes the opposite way: profits are an indication of past innovative success. Patents and innovation lead to increased profit with a 3 or 4 year lag.

There is much contradictory evidence concerning the relationship between size of firm and R&D effort and effectiveness. R&D activity increases with the number of employees up to a level of 5,000. Size up to $75-200 million is also correlated with increased R&D activity (Scherer, 1971,p.361).

In general, the importance of a threshold size has been supported.

Scherer puts forth a number of hypotheses to explain the association of size and R&D activity:

1. R&D, considered as a portfolio investment, would result in advantages to scale as larger firms can spread the risk,

2. economies to scale in R&D activity,

3. economies to scale with respect to other departments in the firm (interaction with other departments may lead to generation of new ideas, marketing channels, etc.), and

4. advantages in process innovation as cost saving processes may have greater impact on large firms with high volume of output.

Another advantage involves ease of gaining government contracts for research. U.S. Federal grants for R&D, for example, are more concentrated than internal funds. Firms with 5000 or more employees undertook 88% of the R&D, this included 93% of the federally supported R&D and 83% of privately supported R&D (Scherer, 1971, p.358).

Among the reasons cited that large size inhibits R&D are the following:

1. decisions are made by individuals not firms so that risk spreading may not be valid, and

2. over-organization of R&D may drive out creative,

imaginative personnel. Fugitives from many firms (e.g. Sperry-Rand, I.B.M., Western Electric) have founded private laboratories. (Scherer, 1971).

The effectiveness of R&D expenditures appears to be negatively related to firm size above a certain threshold (Mansfield, 1964). It was argued that large firms devote a larger proportion of their R&D funds to basic, more risky and longer term R&D projects than do smaller firms (Mansfield, 1969). But it was pointed out (Scherer, 1971) that large firms appear to have an advantage in the lengthy process of making inventions commercially usable. He views the role of different sized firms as follows:

1. small firms and independents play a major role in generating new ideas, and

2. large firms play a major role in development of ideas that require large investments (Scherer, 1971,p.357).

For example, an independent researcher developed the idea for photocopying but Xerox was able to invest the $16 million required for development (Scherer, 1971, p.355). Dupont is used as an example of the effectiveness of large size for innovation. But many of their inventions resulted from purchasing of rights to new ideas. Only 10 or 11 of 25 major innovations in 1920-1950 were discovered at Dupont's laboratories. Dupont was most successful at making process/ product improvements rather than inventing new ideas. This seems a general pattern.

The basic innovativeness of a firm -- its readiness to perceive and act on innovative opportunities -- may be a reflection of its past success with R&D. Firms do what they have in the past been good at doing and avoid activities that have in the past led to failures. This positive reinforcement may also be related to a critical mass required for successful innovation. Ansoff and Stewart (1967) find that below some threshold level, R&D expenditure may be totally ineffective.

In evaluating R&D opportunities, firms make tradeoffs among three classes of attributes: commitment of resources, expected payoff and risk.

Mansfield (1968, p.55) found that the average project size for electrical equipment manufacturers in 1963-64 was $285,000. He also found that the probability that a firm would fund a project was negatively correlated with the size of the investment required (Mansfield, 1968, p.310). Requirements of financial commitment are especially important for small companies or those with constrained access to capital markets, as potentially profitable projects may have to be abandoned before they have had a real chance to succeed (Cooper, 1966,p.175).

The payback period is a measure of the time commitment to a project. The payback period for R&D projects is generally required to be shorter than that for investment in plant and equipment. For all manufacturing in the U.S. in 1961, 55% of the projects undertaken had an expected payback of less than 3 years and an additional 34% were in the

3-5 year range (Mansfield, 1968, p.15). Gerstenfeld (1971, p.22) found that the payback period varied with size of firm: the average was 4.26 for large firms and 3.5 for small. The high proportion of industrial R&D devoted to development and applied research is indicative of this required short payback period (Leonard, 1971, p.236; Bright, 1968,p.6). A maximum payback period may also appear as a constraint imposed by management, thus it may be the deciding factor in project selection (Kotler, 1967, p.30).

A variety of expected payoff indicators are reported to be used by firms. The most frequent criterion is rate of return but other expected performance criteria are used such as impact upon market share, increase in sales, etc. No data on specific average levels of expected payoffs are reported in the literature (see Mansfield, 1969, Disman, 1962, Quinn, 1966, Kotler, 1967, Peterson, 1967, and Allen, 1970).

Risk is an inherent attribute of R&D activities. Risk can be measured by two items: probability of success and patentibility. The probability of success incorporates both technical and commercial uncertainties. As the risk increases, the value of the return and the maximum expenditure justified decreases (Disman, 1962, p.88). The bulk of R&D is relatively safe (non-risky) and aimed at small improvements in the state of the art. Mansfield (1968, p.56) found that the ex ante probability of technical success for projects undertaken averaged 80%. It seems that firms generally do not initiate a project until major technical uncertainties are eliminated. Gerstenfeld (1971, p.22) found a similarly high average of 71%. As basic research projects are more risky than applied, a risk avoiding firm will fund more applied projects (Nelson, 1959, p.304).

Patentability reduces the risk of a project's success by protecting the innovating company from competition. Some firms insist on patentability before undertaking developmental risks (Ansoff, 1965, p.110, Quinn, 1966, p.124). However, Mansfield 1968) postulated that patents are becoming less important as the life cycle for many high technology goods is quite short.

Normative models for R&D project selection and management

Many models have been proposed to analyze the R&D management problem. The suggested models of choice span the spectrum from simple ranking/rating models with minimal data requirements to complex programming models. The simplest models ignore the complexity inherent in the problem. These are the single criteria profitability models. Often projects are ranked by the selected criteria, the highest ranking projects are funded until the budget is exhausted. Scoring models take account of a number of criteria and again rely on ranking projects for selection. Disman's (1962) model is in this category. He proposes to define the maximum expenditure justified (MEJ) for each project. This is fundamentally a present value measure modified by the project's probability of success. The formulae differ depending on the type of project. The MEJ is present value multiplied by the probability of technical success in the case of process improvements, while for new products, the present value is multiplied by both the probabilities of technical and commercial success. The MEJ divided by cost of the project is then an index of desirability (a benefit cost ratio taking account of uncertainty). Projects are ranked by the desirability index and highest ranking projects are to be chosen. The Cranston (1974) model defines another profitability index that depends on estimation of the probability of technical and commercial success modified by a "credibility" estimate. Highest scoring projects are chosen and a project is replaced wherever another has a higher index. Mottley and Newton (1959) propose an index based on five criteria: probability of success, estimation of time to completion, cost of project, strategic need and size of market gain. This model combines consideration of both quantitative and qualitative data. Recognizing that little data is generally available for evaluation of R&D projects, ratings on each criteria cover broad ranges (e.g., probability of success: 1=unforeseeable, 2=fair, 3=high; strategic need: 1=no apparent, 2=desirable, 3=essential). A project is rated on each criteria and the resulting numbers are multiplied to give the project a score. Thus, multiple criteria are recognized but tradeoffs among criteria are not evaluated. In none of these models is any reference made to actual applications, nor is practical justification given for the scoring components. Other scoring models have been proposed by Williams (1969) and Moore and Baker (1969).

Zoppoth (1972) applies system analysis to R&D management at Xerox laboratories. A major part of the paper discusses a system to standardize the definitons of product models for project evaluation (engineering model, pre-prototype model, pre-production model, etc.). This is integrated with a scheme for programme planning and evaluation of technical qualifications and an identification of risk. Another tool described by Zoppoth is DRAM (Decision and Risk Analysis for Management) a risk and utility analysis model for project evaluation (similar to Hertz, 1968). Probability distributions are estimated for company controlled variables (cost, capabilities, etc.). Customer utility variables are defined along with a probability distribution of the relative weights for each criteria. Company controlled variables can be transformed into customer utility variables thus giving the value of any possible product development. Simulations are performed. The first step is to sample from the company variables to derive a "product" which is converted into customer values. Weights for the customer utility function are randomly selected and applied to the product values giving a payoff. Payoff is related to sales (placements) and thus related to revenues and costs to yield net present value. The simulation is performed a number of times to yield the net present value curve. No indication is given how final choice is to be made.

A risk analysis type model for budget reallocation is also presented by Bobis et al (1971). The model has been used as an aid to decision making by the Organic Chemicals Division of American Cyanamid Company. The modelling led to a more farsighted portfolio. The 1967 model budget called for a major redistribution of the research effort and the

1970 budget closely resembled this distribution.

The procedure calls for estimates of the probability of completion and success for each expenditure level (research curve for the project) and estimates of annual sales for each starting year. These are combined to yield expected sales and probability for each expenditure level. This then explicitly displays the trade-off between increased expenditures and increased funding. Data requirements for the research curve are minimal: the research curve (a logistic curve) can be estimated with only three observations: most likely, optimistic and pessimistic costs. A scoring model was developed to estimate the probability of technical success (five criteria with three classes each). It is not specified how the ratings on the criteria were aggregated but it appears that a simple linear model was used.

The solution technique is not straightforward. The optimization procedure was described in Atkinson and Bobis (1969). The objective is to select a portfolio overtime to maximize the expected return given annual budget constraints where the annual budgets depend on expenditures in previous years. An iterative scheme is used to solve the problem. The consideration of the possibility of an infinite variation in allocation to each project makes it very hard to solve the model. It would appear that this model would be unsuitable for laboratories with more than a few projects to consider and even in these limited cases, the solution procedure is difficult.

The rating models serve as the criteria for more structured choice models which consider explicitly resource constraints. One of the most computationally effective optimization methods available for constrained allocation problems is linear programming. LP models enable the explicit maximization of an objective function and permit consideration of a variety of constraints in addition to the budgetary one. The solution is in the form of the entire optimal portfolio. A short coming is the lack of consideration of indivisibilities (in the LP framework, a project can receive funding in any proportion that is optimal, even if that makes no sense in terms of the project). Integer programming recognizes the inherent project indivisibilities but losses the relative ease of computation of the LP formulation.

An example of an LP model is described by Moore (1974). The model was tested on U.K. Department of the Environment, Highway Safety data. The problem is to select a portfolio of highway safety projects. The objective is to maximize the expected benefit/cost ratio by optimal selection of projects. Net benefits are defined as monetary value of a decrease in traffic deaths, personal injury and property damage by increased highway safety (B) minus the research (R) and implementation (I) costs net of any other losses (L) that may occur (e.g., decrease in deaths may be replaced by increased injury).Costs can be defined either as research costs alone or research and implementation costs depending on the relevant constraints. Uncertainty is included by the estimation of probability of success and probability of implementation; these are applied to cost and benefit calculations to derive the expected net benefit/cost ratios. The values B, I, R, and L are estimated through interviews: subjects are asked to give most likely, optimistic and pessimistic estimates, which are weighted to derive the estimates. The planning period was 1972-2000 and a 10% discount rate was applied. The choice set included 41 on-going projects, 36 variations of these projects, and 21 proposed projects. The constraints included budget and manpower constraints, and the requirement that mandatory projects be undertaken. It was not explicitly stated but integer programming would be required for solution of the problem as formulated as constraints require that not more than one version of a project be selected and that the version chosen, be funded fully.

Nutt (1965) describes a model designed in the Air Force Flight Dynamics Laboratory. The programme is designed to handle the following attributes of R&D project portfolio selection: needs of the air force for various systems development, probability of success, capabilities of research team, degree of support by project for each task, contract out versus in house development, relationship of support to progress and cost. The objective is to select a portfolio to maximize the total R&D effectiveness (RDE) derived from the budget. The data requirements are substantial though Nutt states that all the information should be collected in any evaluation effort. A mission matrix must be defined giving the system needs of the air force and each mission must be given priority values. Each project must be evaluated in terms of its system contribution, probability of success, and capability of the laboratory to attain the required technological advance. A 10-year time horizon is used. Six 10-year plans are generated for each project. The first is based on the planned resource expenditures, another uses half the resources and the third uses double the resources. A computer model interpolates to define the remaining three project plans. The value (RDE) of each project version is a function of the rate of expenditure, distance from the state of the art and timeliness of completion of the project compared with air force goals. The RDE for each project version is defined to be the increased probability of success achieved in the budget period, weighted by the contribution to the goal and the importance of the goal served plus the increase in the confidence level (technical capability) of achieving the goal. Constraints include total budget for in-house and contract research, and contract and in-house engineers. Qualitative aspects such as capability of achieving technological advance and probability of success are recognized. Indivisibilities are handled by defining six project levels, though the interpolation may not be valid (if six, why not an infinite range of versions). The model is a method of collecting and organizing data about the projects. The data bank itself can serve the function of after the fact evaluation of research progress and research effectiveness.

Cochran et al (1971) describe an integer programming model that has been implemented by the Smith, Kline and French Laboratory to aid management in R&D decision-making. The aim of the model was to recognize the unique problems of the pharmaceutical industry: long lead time (10 years) from conception to commercialization of product couplied with high product attrition rates and high R&D costs. The model has two components: project evaluation and portfolio selection. The project evaluation component reduces the economic data for all projects to a single dimension the expected net present value (ENPV). This calculation requires an estimate of the cash flow from the project, the probability of technical success, and the capital discount factor. A 10-year product life is assumed. The management team for the project estimates the cash flow. The capital cost is the sum of the expected corporate growth rate and the dividend yield (reflecting return to attract new stockholders). The actual calculation of ENPV is unique, accounting for differing probabilities relating to costs and returns: initial outlay is certain and weighted one; future outlays are less certain as project could be terminated, the weight applied is the average of one and the probability of technical success; returns are uncertain and are weighted by the probability of technical success:

$$ENPV = x_1 + \left(\frac{1+p}{2}\right) \sum_{i=2}^{k} \frac{xi}{(1+R)}^{i-1} + p \sum_{i=k+1}^{n} \frac{xi}{(1+R)}^{i-1}$$

Where p is the probability of technical success, R is the discount rate, and x_i is the net return (negative for costs) of the project in period i. The model allows for sensitivity analysis of ENPV with respect to cost and probability estimates.

The portfolio selection component takes the ENPV data and selects a portfolio to maximize total ENPV subject to fixed budgetary constraints. An integer programming algorithm is used. Budgets are specified for a number of years (the planning horizon). The model is conversational and user oriented. If a project not included in the portfolio is judged mandatory despite low ENPV (i.e., it is selected for non-economic features) the budget variation feature enables a recalculation of the optimal portfolio - netting out mandatory projects from the project list and costs from the budget. This feature makes it easier to sell the model to managers who recognize that non-economic criteria are also valid. Some limitations of the model are: (1) only few projects can be considered, (2) only single versions of the projects are considered and (3) though possible termination of projects is recognized in the calculation of ENPV, there is no feedback loop to initiate termination and substitution of other projects within the planning horizon. The discounting of the future costs is incorrect, making the projects seem less costly than they actually are. It would be better to include the full costs in the ENPV, discounting only the benefits by the probability of technical success.

Grossman and Gupta (1974) describe a mixed integer model that is used in the Johnson and Johnson pharmaceutical company. The aim is to develop a portfolio selection procedure to account for different types of research activities (exploratory, developmental, and product support). This model is more general than the Cochran et al. model: multicriteria are collapsed into a utility measure that incorporates more than present value, parallel strategies and interrelation among projects are considered, new and old projects compete for funds over the planning horizon, various funding levels of projects are defined, mandatory projects are also considered but they need not commence in the initial period of the plan. The model makes use of decentralized and specialized information of different units in the organization in calculating project value. The model is iterative and requires management participation.

The first phase requires data generation for each project. A novel approach here is to define "families" of projects. The families reflect parallel strategies of development or exploratory research. This feature is a recognition that working on project development from a variety of ways increases the probability of technical success; this is accounted for by Bayesian methods. The project list then includes pseudo projects that are combinations of projects in the same family. Multiple project levels (normal, accelerated, delayed) are defined for projects and pseudo projects.

The assessment of project value utilizes a rating mode - various attributes are defined (e.g., growth potential, marketability, competitive products, contribution of new technology to corporate image, stability, productive ability with respect to various resources). Executives and other qualified individuals rate the project on these dimensions on a five point scale giving information only where they feel qualified. The rating task for each individual is relatively easy. This information is then aggregated into a utility value for each project.

The objective is to select a portfolio of projects and pseudo projects to maximize utility over the planning horizon. Initiating times are selected for each project. The constraints account for selection of only one version of each project and only one initial period. If a project is mandatory equality constraints apply and the programme selects the optimal period for commencing the project. Other constraints relate to budget and manpower availability.

Not enough detail is provided concerning properties of the model to comment on the ease of computation and the capacity of the model. It is an interesting attempt to model complex aspects of the R&D management problem. No documentation, however, is supplied for the selection of the criteria that make up the utility measure nor how tradeoffs among criteria and individual judges are handled given the decentralization.

Another integer programming model, somewhat less general but adapted to special problems, has been developed for use at BISRA (British Iron and Steel Research Association). This is an industry research group and as such has special problems: its raison d'etre is to perform research that would not otherwise be undertaken by individual firms in the industry and then to 'sell' these projects to the industry. The model development is reported in Reader et al. (1966), Collcutt and Reader (1967) and Beattie (1970). The approach that has evolved is the use of integer programming with subjective evaluation of probability estimates of technical success. The benefit/cost ratio is the criteria used for evaluating projects. The benefits depend on diffusion of the innovation throughout the industry compared with diffusion if BISRA had not undertaken the project and later someone else did. It is assumed that diffusion is faster due to BISRA involvement for two reasons: (1) the project is undertaken sooner, and (2) the BISRA selling campaign increases the speed of diffusion. The two diffusion paths are estimated assuming logistic diffusion curves. The discount rate varies with the project type. Two types of projects are recognized: those resulting in annual savings to firms in the industry and those resulting in once and for all capital savings. Annual savings affect central funds availability, the discount rate applied is 12% in real terms. Capital savings affect large capital issues valued at a discount rate of 7%. The benefits are weighted by the possibility of technical success estimated by project leaders. Costs are marginal costs and do not include overhead. Project variations are defined utilizing different research team sizes. Benefits, costs and probability of success all depend on team size allocated to the project. To compare long and short term projects it is assumed that a research team assigned to a short project spends the remaining time in the planning horizon working on fill-in projects. Thus the total benefit of the project includes the benefits of the fill-in projects. (Reader et al, 1966). Integer programming is used to select the portfolio of projects. The objective is to select projects to maximize the net benefit of the portfolio subject to manpower and budget constraints. Constraints include selection of only one version of a project, mandatory projects that must be selected in one version and contingent projects where if one project is selected another must also be selected. Thus some project interdependencies and non-economic choices are recognized (Beattie, 1970). Constraints can be expanded: 1) to require that specialists be assigned to their specialities (to maintain group morale, staff satisfaction constraints), 2) to guarantee prestige by requiring that at least one prestigious project be selected, and 3) to insure diversification by requiring that at least three projects are selected (Reader et al, 1966).

Beattie (1970) feels that in use, the system has been worthwhile. Projects that were initially thought to be worthwhile have been found to be uncompetitive and have been terminated. Some data is hard to collect, but modifications are being made to increase the ease of data collection. Though the costs of implementing the model are high (2-3% of the budget, the returns are substantial (Beattie,1970, p.290). The main benefit has been a better organization of the work, with the use of larger work teams to speed up completion of projects. The model could be improved by allowing sequential choice of projects rather than relying on fill-in work to complete the portfolio.

Bell and Read (1970) developed an LP model for R&D portfolio selection with uncertainty. Their model is based on probabilistic networks. The model is used at the Central Electricity Generating Board and at the Gas Council (England). As with the BIRSA model, the benefits relate to use by industry of the innovations. The actual form of the benefit function is not clearly specified. Three versions of each project were defined: slow, medium and fast. The constraints account for the requirement that "key" personnel be included on some projects. In practice, 20-40 projects with 40-100 versions are generated. Some projects are designated mandatory. The model is solved using LP though this meant that some projects were accepted at partial levels. As it does not necessarily hold that partial projects yield the same fraction of benefit, an interative procedure was used to derive the final portfolio. In theory, integer programming could be used but is computationally difficult. Sensitivity analysis was also run with variations in the discount rate (basic rate 8%) and changes in the time horizon (basic time 10 years). Only a limited number of projects were affected by these changes.

Lockett and Freeman (1970) also develop a network model to account for the stochastic nature of resource requirements and project benefits. They apply the model to a case study based on data from an industrial R&D laboratory and compare the solution with that obtained from an expected value model. The example used was small, containing only nine projects and the results obtained were similar to those from the expected value solutions. The authors feel that this evidence validates the procedure though it seems that this adds credence to the easier to solve expected value models.

The assignment model developed by Beged Dov (1965) is another example of LP applied to R&D management problems. The problem is how to assign N selected projects among n teams (or laboratories) of researchers. The problem formulation requires three assumptions: 1) projects can be classified into a small number of groupings by similarity, 2) most teams can work on all the projects with varying efficiency (different costs and time to completion), and 3) it is possible to estimate the costs of researching each project by each team or at least to estimate relative costs. The objective is to allocate projects to teams to minimize the total cost of researching the portfolio subject to constraints on the number of projects each team can handle and the budget that may be allocated to each team. The problem is formulated as a transportation problem to take advantage of the existence of efficient solution codes.

Dynamic programming (DP) models take account of time dependent returns and can consider the needs for project reappraisal throughout the planning horizon. Decisions made in one period will affect the system and decisions in the future. Thus DP can increase realism by modelling the sequential aspects of decision making, accounting for the fact that initial commitments for exploratory research are less than the final commitment for project commercialization. The solution method is recursive. Data requirements are more complex than for LP models and the solution techniques are more difficult.

Hess (1962) focuses on the sequential nature of the R&D management problem: a decision to initiate a project is not a commitment of further allocations. He considers R&D activity as a purchase of information. Thus R&D provides better information on which to base future decisions. The objective is to choose a sequence of budget allocations over time to maximize the total expected discounted net profit (maximize the present value of the expected cash flow) from the total R&D budget. R&D projects are considered completed when technical success is achieved. Therefore, projects are terminated before the assessment of economic feasibility. With this definition it is not clear how the present value is derived. Net profit is dependent on the period in which technical success is achieved and decreases as time increases. He considers that there is some period beyond which technical success is irrelevant and the project should not be commercialized as it will result in losses due to competitive considerations.

Hess develops models with and without budget constraints and with probability of technical success dependent and independent of previous research. He attempts to get an expenditure stream that coincides with that observed in practice, i.e., increasing expenditures over time. Therefore, he prefers forms of the model that have this characteristic. No example is given so it is hard to assess the difficulties of data collection. Time dependent income streams and probabilities of success are required and these may be hard to estimate. No indication is given of the size of the problem that could be handled by this method. General analytic solutions are not available for all models; for example the model with budget constraints and time dependent probability of technical success can only be solved numerically and in the case of a large problem this would not be feasible.

Dean and Hauser (1967) develop a programming model with the capacity for handling a variety of objectives. They model the hierarchical structure of the problem which leads to sequential decision making. The model is applied to a military R&D problem which has three levels: 1) the overall system to be developed, 2) materiel concepts or components of the system; and 3) possible technical approaches to developing the components. Step 1 involves choice of the technical approach to maximize the probability of achieving the materiel concept. Step 2 requires funding of the component concepts to maximize the probability of achieving the system. Step 3 involves allocation of funds across systems to maximize the total value of the R&D output. Data for steps 1 and 2 are probability of success and costs, and for 3 the payoff or value of each system to the military objectives. Value is measured by military priority of having the system. The model was solved for many levels of budgeting: Step 1 was solved at $10,000 increments, steps 2 and 3 at $100,000. The model was solved for nine criteria. These reflect interaction with decision makers who when they do not like the optimal portfolio of systems funded suggest other constraints to modify the solution. For example when some systems were not funded, they suggest a constraint that all systems be funded at some level to maintain continuity of research. The model enables easy analysis of cost effectiveness of the various programmes.

Souder (1972) develops a planning and control system that is used at Monsanto Company for aiding R&D decision making. Dynamic programming is used in the planning model. Cost effectiveness is used in the control model. Probability of success in this model depends on the level of funding. A four question procedure is developed for estimating the probability of success. Questions relate to familiarity of the problems to be encountered, availability of technology and reliability of cost estimates. The relationship of the expenditure level (budget/maximum budget) and the probability of success depends on the pattern of yes-no responses. Two objective functions are considered: 1) maximize the expected net return on R&D investment and 2) maximize gross return from R&D investment. The model solution gives project selection, project scheduling and project funding.

The control model relies on statistical quality control. Variance is measured between actual performance and planned performance. If the variance is above a critical level then a decision is called for. Three control variables are suggested: cost variance, progress variance (probability of success), and cost/progress variance.

Data was available with some modifications. A 10-year planning horizon was required with the same degree of confidence in data for all projects. PERT diagrams (decision trees) are used. Difficulties arose in determining actual probabilities of success to compare with expected as administrators are often unable to assess the actual status of projects immediately. Therefore, Souder defined a new measure that relates to the weighted percentage average of milestones attained. This requires detailed flow charts of projects and knowledge of all milestones or information bits required for successful completion. Collection of this data would be difficult and costly. The model serves best for evaluation of projects that are neither exploratory (not enough data beyond day to day activity) nor developmental (planned relatively easily with other models). The model was in use for one year and then the DP aspect was abandoned though the PERT analysis and control phases are still used. The DP models generally are hard to understand and data requirements are not easy to interpret (e.g. actual status of project).

Kepler and Blackman (1973) use DP to solve a simple example (four basic activities, four optimal activities) where the problem is to reallocate resources as the result of a budget decrement. Three utility functions are considered. The DP solution is shown to be better than the conventional solution of equal percentage cost reduction over all projects. No comment is made on the relative costs and ease of data collection or the problems that would be expected in solving a more realistic larger problem.

Charnes and Stedry (1966) suggest that R&D is characterized by break throughs and other emergencies (e.g. competitive environment). These events of low probability place high resource demands on the system when they occur. Therefore, R&D management requires an adaptive planning mode; one that can respond to new information between planning periods. They develop a chance constrained model of two stages - planning and control process - which allows for 1) random availability of facilities in the short and long run; 2) random occurrence of emergency demands at random times during the short run, 3) probabilistic constraints on conformity to availability constraints and emergency demands, and 4) deterministic constraints on desired activity levels.

A number of realistic possibilities occur in the solution: 1) if the binding constraints reflect research needs, then there is no change in the plan, 2) if the binding constraints reflect facility availability, then there is lessened activity (to protect against an emergency create slack in the system);and 3) there is increased activity if the constraints on facilities are not binding to hedge against emergency.

It is not clear what size problem can be handled. Some of the data may be difficult to collect and interpret such as the probability of an emergency in each research field.

Lockett and Gear (1973) propose a method of R&D portfolio selection that combines decision tree analysis, simulation and linear programming. For each project a stochastic decision tree is drawn. Resource requirements of each path and in each time period are specified as is the distribution of net benefits associated with each end point. (Gear et al, 1972 have discussed the process of describing a decision tree for individual R&D projects, also see Raiffa, 1968 for the general theory). This procedure models the sequential nature of R&D project evaluation. It also enables the analysis of the parallel approaches. The procedure is flexible and allows for consideration of uncertainty in project duration, resource requirements, project outcomes and project value by the appropriate definition of the branches.

The problem is how to allocate resources in period 1 in order to be on an optimal path in the future. Various solution techniques are possible. Lockett and Gear mention three: stochastic programming, chance constrained programming and simulation combined with LP. For ease of computation, they select simulation plus LP and describe the process: sample at each probabilistic node, this yields project paths, given a set of paths for all projects, solve an LP or integer programming problem. After many such models are solved, search the solutions for stable patterns. The output of the procedure is a number of alternative portfolios with distributions of benefits and probabilities of violating resource constraints from which management can choose. They present an example using six projects and thirteen versions, with only one resource constraint. For this small example the results are similar to that from a stochastic linear programming model (where only one portfolio would be presented in the final output). However, for large scale problems the stochastic programming model might not be practical (see Wets, 1976, for algorithmic techniques).

The procedure was also applied in an industrial laboratory. That case study had 37 projects, 65 decision nodes and 40 chance nodes, 4 time periods and 6 resource categories. Chance nodes were sampled 100 times which is not really sufficient for reliability of estimates. The procedure for portfolio selection is ad hoc. In this case two attempts were made. The first approach involved rounding project levels to 0 or 1 and searching for a frequently occurring portfolio. However, there were 72 portfolios each occurring with the same frequency. The second method ranked projects by overall mean of occurrence (average fraction of project selected) then funding projects until the first resource constraint is reached. The procedure is ad hoc and there is no indication that the portfolio selected is optimal or even good. The characteristics of the solution are not known. This procedure is too technical given the ad hoc nature of the solution. It appears that a better solution procedure would be to formulate the problem as an integer programme with 65 decision variable, 24 constraints (6 in each period), utilizing the expected values defined for the chance nodes.

Optimal control models are specified when there are certain variables that guide the evaluation of a system continuously or at discrete intervals over time. Solution of the problem requires the selection of these variables to minimize an objective function. Problems are solved by successive approximation and convergence is not guaranteed unless certain convexity assumptions are met (Zangwill, 1969 and Wilde and Beightler, 1967).

Lucas (1971) describes a continuous time control theory formulation for single project evaluation. The project is assumed to incur costs during a period (O,T) and returns are discounted to time T (not the initial period of the investment horizon!) Four cases are generated depending on uncertainty with respect to time and costs: time to completion can be known or unknown, costs can be fixed or variable, i.e. decreasing in T. The objective function is to maximize the present value of the project if time to completion is known or to maximize expected present value if completion time is unknown. When costs are known they are used in the solution. When costs are variable, the optimal level of expenditure is determined at each time period using optimal control theory. Assumptions of the model are: returns on project completion are independent of expenditures and time to completion (i.e. rules out the case of rivalry), uncertainty as to completion time is most important (successful completion and payoff on completion are deterministic) and varying expenditures will affect progress toward completion. The solutions have the following characteristics:

1) Costs and Time known: solution similar to investment decision, undertake if net present value is positive.

2) Time known, Costs controllable: present value increases as time to completion nears, therefore it is optimal to increase expenditures over time.

3) Costs known, Time unknown: undertake project if mean net present value is positive. It is not optimal to use the expected time to completion as the answer depends on the probability distribution of time to completion.

4) Costs controllable, Time unknown: completion time is dependent on the expenditure plan. Contingency plans are necessary to determine how expenditures will vary with changes in uncontrolled variables, in this case total required effort.

Though analytic solutions are provided, the model is not applied to any real project. Data collection would probably make these models unattractive. Model 4 seems most realistic with respect to cost and time uncertainties (models 2 and 3 do not seem realistic, model 1 is the trivial case) but would be difficult to apply.

Optimal control models of R&D management have also been developed by Kamien and Schwartz (1971, 1974). In the first model they consider the uncertainty with respect to time or effort to completion similar to Lucas. This is called technical uncertainty. The second model takes account of both technical and market uncertainties (rival behavior) so that cash flow (benefit) expected from the project is uncertain and dependent on time of successful completion of the project. As stated in the first paper "the objective . . . is not to furnish guidance for R&D managers but rather to provide a theoretical rationale for two basic expenditure patterns which might be empirically observed" (Kamien and Schwartz, 1971, p.61). The models would be difficult to implement i.e., data requirements such as the relationship between the level and rate of expenditure on accumulated effort and time to completion are rarely available. The expenditure patterns justified are: 1) increasing annual expenditures (if the completion rate is a non-decreasing function of total effort) and 2) initially increasing then decreasing annual expenditures (if the completion rate is initially increasing up to a certain amount of total effort and then decreasing). Under rivalry, expenditures are made until some firm successfully completes the project: that firm collects the benefits and the others lose all. Rivals are recognized by a single subjective probability distribution over introduction date of competing products. The objective is to maximize the expected value of the project. The addition of rivalry to the optimal control model does not change the form of the solution. It does, however, lower the expected value of the benefits of the research (the probability exists that a rival will complete the project first) and thus may make some projects unprofitable. Again, implementation of this model would be very difficult.

Implementation problems of R&D decision models

Quantitative R&D project management techniques are not in general use. Many managers have expressed interest in having decision aids and many models have been developed, however, few have been implemented. There is not enough known regarding the evaluation of the usefulness of the various models. An organization does not know in advance the implication of implementing various models. Souder et al (1972) provide an approach to the assessment of the value of the models as decision aids. They report on two quasi-experiments designed to test the potential usefulness of R&D management techniques. The first experiment was carried out in an R&D department where the objective was to develop new products and improved products. A dynamic programming model of portfolio selection was introduced to the company (see Rosen and Souder, 1965). The objective of the model was to choose a portfolio to maximize total expected net profits given fixed resources. The data requirements included estimates of project life, maximum and minimum annual expenditures and present value of profits. The output was an initial allocation of resources for the first year. This would be periodically updated when new projects were proposed, or when data estimates changed. The model served the purpose of integrating information of the various departments in the company. They report that the model was an important analytic tool, helping to clarify objectives and constraints of individual departments and focusing attention on needed data.

The second experiment was undertaken in an R&D laboratory where the major concern was exploratory (and therefore riskier) research. The model implemented was a modification of Hertz's (1968) risk analysis model. The method requires the construction of uncertainty profiles for the key factors. The outcomes considered included anticipated technical or research achievement, market opportunity, market penetration, and profit margin. A group would meet to evaluate individual projects. Then projects would be ranked in order of profitability given risk. Probability distributions for each possible portfolio were developed. This seems to be an incomplete application of the Hertz method that would normally rely on simulation and estimation of the utility function. Without this the model served only as a guide to selection, a means of organizing data. The manager is still left with the difficult task of selecting among many possible portfolios without a guide.

Their main conclusion from these experiments is that R&D management models can induce the collection and exchange of data, improve use of communication channels and increase integration of departments in an organization.

The lack of consideration of group process is another key factor in the limiting use of quantitative models for R&D project/portfolio selection. Experiments by Souder (1974, 1975) and Helin and Souder (1974) take group processes into account and investigate methods to obtain group consensus in R&D project selection. Helin and Souder (1974) report on a Q-sort technique for qualitative group project selection. The procedure involves a cycle of activities: 1) each individual sorts items (projects) into five groups by "worth", 2) group discussion period, and 3) phase 1 again until consensus is reached. The criteria (worth) is the priority of each project. For the experiment 13 projects that were being undertaken were selected. Each was given a code number and title for description. No characteristics (i.e. measures or criteria values) were given. This technique is feasible only where the projects are familiar and some underlying consensus exists to begin with. The experiment showed that the Q-sort technique was not very useful in project selection. The method was too imprecise and the procedure would not be useful when many projects are involved.

Maclay (1974) in comments suggests that criteria should be listed, making the technique more useful for analyzing new projects that are not familiar to the participants. A rating table would be used. Each participant would enter ratings for all the projects for each of the criteria, the average rating would be calculated and placed in the center.

Then an attempt would be made, without a formal model, to enter overall priority ratings for the projects (a consensus rating). This method too would be of limited usefulness due to the complexities of comparing many projects on many attributes without a formal model.

Experience with these qualitative models would indicate that a mixture of modes would be useful. The number of comparisons necessary prohibits use of group processes for project evaluation. Group processes could be designed to reach consensus on organizational objectives and weighting schemes. This information could then be used with quantitative optimization models to select R&D portfolios.

Souder (1974b, 1975b) describes some experiments aimed at obtaining group consensus for project selection criteria. The first paper reports on an impact method for determining criteria priority. The experiment used paired comparisons, group discussion and interaction to achieve consensus in R&D project selection in four organizations. Two of the four groups actually achieved consensus. The procedure had the following steps: Step 1: solicit selection criteria from each participant. Step 2: have individuals make paired comparison rankings of own criteria using a tableau with the criteria forming both the rows and the columns. Column criteria were compared with row criteria. If column criteria is preferred to the row a "+" is entered, if dominated a "O" is entered. The priority criteria is that with the highest number of ones. (Consistency is met if the number of +'s equals the number of O's). In step 3 group paired comparisons are made. Steps 2 and 3 are done in the same session.Compared with the Delphi technique, the impact method made explicit use of group pressure in arriving at a consensus.

The second paper compared three techniques for achieving consensus: 1) the impact method (combined Delphi and interacting), 2) Delphi; and 3) interacting. All procedures begin with each individual developing a list of criteria. The three techniques are variations on a two phase procedure. Step 1: each individual ranks criteria and states justifications, this information is exchanged. Step 2: the lists are compared in a group, the group interacts and prepares a group list of criteria and ranking. The impact method is cycling of steps 1 and 2 carried on three times. The Delphi method is step 1 carried on three times. The interacting method is step 2 carried on three times. Nine R&D and marketing groups chosen at random participated in the experiment. Leaders were created for each group to control for leadership style (another variable). It was found that the impact model was best for achieving integration and/or consensus between R&D and marketing divisions. The test of the experiment would be better carried on with actual representatives of marketing and R&D from the same company participating as a group, given the existing roles and interactions consensus might not be as easily reached as with the random groups. Also given the number of variables (two leadership, two group structures and three modes of interaction) the sample was too small for any conclusions to be drawn. Analysis of values of alternative models for particular organizations and executive groupings is only a first step toward the study of implementation (or non-implementation) of proposed normative models. Clearly a more universal theory of diffusion and implementation is necessary. In the conclusion, an attempt is made to identify some of these key problem areas important for inducement policy design in the R&D field.

Conclusion

We have described the existing inventory of knowledge of patterns of R&D investment decisions, government impacts upon them and the normative proposals for improved decision making. If better fit between target populations and either government inducement policies or management improvement strategies is desired, this mosaic of information is incomplete. There are four broad areas in which information is scarce but necessary for strategic design. They are:

1) information about the nature of selective perception processes of R&D decision making,

2) the objective functions (explicit and latent) which guide choices among alternative R&D investment opportunities,

3) the impact of R&D upon the positions of prime bargaining units in organizations, and

4) the impacts of organizational structure and processes upon implementation of investment decisions.

The first two categories of information relate to the question of what different decision units consider relevant in defining their problems and what they value. The last two categories relate to the organizational impact of R&D and the processes by which decisions are reached and implemented. These areas provide a focus for required additional research aimed at improvements in R&D decision making.

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