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The Federal Make-or-Buy Policy: An Analysis
of Factors Affecting the Efficiency of the
Government R&D Contracting-Out

by

Atipol Bhanich Supapol, B.A., M.A.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Doctor of Philosophy

Department of Economics

Carleton University

Ottawa, Ontario

1988

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the Efficiency of the Government R&D Contracting-Out"

submitted by
Atipol Bhanich Supapol, B.A., M.A.
in partial fulfillment of the requirements
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ABSTRACT

The federal Make-or-Buy policy established in 1972 specified that all new mission-oriented research and development be contracted-out to private industry. This policy was a direct response to the report of the Senate Committee on Science Policy which contended that Canada was getting insufficient pay-off from its research and development effort, principally because research and development conducted within the government was seldom exploited commercially. The contracting-out of research to private industry would, in the view of the Committee, increase the awareness by the private sector of opportunities for commercial exploitation.

This study establishes an analytical framework within which the benefits and costs from contracting-out can be assessed. It then investigates systematically the variables which affect the efficiency of R&D contracting-out and attempts to identify the circumstances under which contracting-out implies a net allocative gain. Determinants of the contracting costs are examined. The crowding-out of private R&D issue is addressed and the nature of resources absorbed by government contracts is analyzed. R&D contract outcomes as they relate to the characteristics of the contractor, the characteristics of the contract, and the nature of the research work are examined, and the determinants of the probability of a commercial spin-off are identified. Single and simultaneous probability models (LP and LOGIT) are estimated using a unique Canadian data base, consisting primarily of survey information gathered from R&D contractors and government project officers as well as firm specific information from Statistics Canada.

Empirical results indicate that, while selective contracting-out can increase commercial pay-offs, it may also imply a lower probability of achieving government research objectives and higher R&D resource costs. Additional investigation is required before one can pronounce on whether contracting-out has been beneficial on balance.

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Chapter 1

Introduction

1.0 Introduction

The argument that the private enterprise system has a tendency to underinvest resources in research and development is generally well known. In an important and widely cited essay, Arrow (1962) pointed out three of the classic reasons why private incentives for research in certain areas may be lacking: indivisibilities, inappropriability and uncertainty. All of these are possible reasons for the failure of the competitive system to achieve a socially optimal resource allocation. Recently, however, a number of papers have demonstrated theoretically circumstances under which a competitive system may produce incentives that lead firms to overinvest resources in innovative activities. These papers include Hirschleifer (1971), Barzel (1968), Kamien and Schwartz (1972), and Dasgupta and Stiglitz (1980).

Notwithstanding this opposing view, the thrust of public policy is to encourage industrial R&D. Support of industrial research and development also appears to be justified by empirical evidence which indicates that social rates of return to inventive activities greatly exceed the corresponding private rates of return. Mansfield et al (1977) show that the average and marginal social rates of return for industrial R&D tend to be very high, often 30 per cent or more; implying that there is underinvestment in R&D in the private sector and that the allocation of additional resources to inventive activity is socially desirable.

With evidence of this sort, various governments have suggested a variety of measures to modify the present system and encourage industrial

R&D expenditures. Many of the proposed programs are designed specifically to increase the incentive to private innovative activity by increasing directly the private rate of return from R&D and/or lowering the cost of performing R&D. Other programs redistribute R&D funding and/or performance. Over the years, large amounts of research and development funds have been supplied by various governments.

Table 1 shows the percentage of the total R&D expenditures that is financed by the government for Canada and other OECD members. Only those countries whose Gross Domestic Expenditures for R&D is at least 1 percent of the country's Gross Domestic Product are presented.

Table 1

Gross Expenditures on Research and Development by Business and Government.
Selected OECD Countries, 1977

	GERD/GDP ¹	Sector performing R&D		Government funding of total GERD	Share of government-financed R&D performed by government
		Business	Government		
		(Per cent)			
United States	24	66.8	15.3	51.0	30.0
Switzerland	23	75.7	6.8	21.1	32.2
The Netherlands	20	51.7	20.8	22.7	91.6
West Germany	21	65.0	16.1	44.2	36.4
France	18	60.3	22.3	37.7	59.2
Japan	19	57.8	12.1	16.2	74.7
Belgium	14	67.9	11.4		
Canada	11	37.3	30.3	45.7	66.3
Italy	10	53.6	24.6	47.8	51.1
Norway	14	47.1	18.4	33.5	54.5
Finland	11	51.9	26.3	30.5	86.2
Australia	10	24.8	50.9	54.1	94.0

¹ Ratio of gross expenditures on research and development (GERD) to gross domestic product (GDP)
Source: A. B. Supapol and D. G. McFetridge, "An Analysis of the Federal Make-or-Buy Policy," Economic Council of Canada Discussion Paper 217
Ottawa 1982

An examination of 1977 R&D activity suggests that government financed R&D represents a significant proportion of the total R&D in most nations. For Australia, Canada, Italy and the United States, over 45 percent of the total R&D is financed by government funds. The structure of the available funds shows that the amount devoted to Natural Sciences and Engineering in Canada is comparable with other OECD nations, and in terms of government funding, Canada ranks somewhere in the middle to high with 45.7 percent. However, as Table 1 indicates, Canada ranks next to last in terms of the proportion of its total R&D effort performed in the business sector. Moreover, in Canada 66 per cent of government funded R&D was performed within the government as opposed to an average of 32 per cent for the U.S., Switzerland, Sweden and Germany. The country with the highest ratio of direct government funding is Australia with 54.1 percent, while Japan with 16.2 percent, is the country with the lowest.

To improve the scientific capability of the Canadian industrial sector and to promote greater research activity in that sector, the federal government has enacted, over the years, numerous programs to provide an environment more conducive to industrial R&D. The major programs include: the "Make or Buy" program, a contracting out policy for research with definitive goals; the Technological Transfer programs, such as the Pilot Industry - Laboratory Program (PILP) formulated to assist in the application of government research and help Canadian companies recognize specific industrial opportunities arising from government in-house R&D projects; and the federal industrial assistance programs, a series of R&D inducing mechanisms ranging from indirect incentives - tax deductions or tax credits to direct financial incentives such as research grants and subsidies - the

Enterprise Development Program (EDP) and the Defence Industry Productivity Program (DIPP). These are a set of policy tools intended to increase incentives to private R&D.

1.1 The Make-or-Buy Policy and its Origin

1.1.1 The Make or Buy Policy

The Make or Buy policy, enacted in 1972, stated that all new mission-oriented research and development programs undertaken by the federal government in the natural sciences should be contracted out to Canadian industry. Mission oriented research and development is defined as "research and experimental development, minus free basic research, plus feasibility studies." The directive applies to all departments and agencies listed in schedule A and B of the Financial Administration Act (Ministry of State for Science and Technology, 1976). Not included in the policy were on-going research and development projects and new or existing research and development activities of some government departments.

In 1974, the policy was extended to cover unsolicited proposals from the private sector in support of government science objectives. The Make or Buy policy was subsequently expanded to include some new and on-going R&D, as well as other scientific activities. Furthermore, the unsolicited proposal program was broadened to include projects deemed to satisfy priority science and technology requirements in general, and not only those in support of departmental science missions. This expanded version of the Make or Buy policy is currently known as the Contracting-Out policy.

Little work has been done on the analysis of the Contracting-Out policy in Canada. One of the reasons for this is that very little relevant

contracting-out data has been compiled. In this study, I present new evidence on the actualities and results of the contracting out process. The purpose is to shed light on some of the issues and problems of contracting-out, and to provide empirical insights into dimensions that are lacking in the existing literature.

1:1.2 The Origins of the Contracting-Out Policy

As early as in 1968 with the Science Council, and in 1970 with the Lamontagne Committee, the government's position as the predominant performer of Canadian research and development has been criticized. In its report, the Senate Special Committee on Science Policy (Lamontagne Committee) concluded that, a larger proportion of government financed R&D was performed within the government sector in Canada than in any other industrialized country. It also demonstrated that federal financing of extramural R&D had been directed more towards the academic sector rather than towards the industrial sector. As a consequence, the involvement of the industrial sector in R&D remained relatively weak (Meyboom, 1974). In the committee's opinion, scientific performance was unevenly distributed between federal in-house and the industrial research establishments and this led to the government's selection of inappropriate research and development projects, and the inadequate commercial exploitation of research results.

To help overcome these problems, the Science Council as well as the Lamontagne Committee advocated that industrial involvement in federal research and development activities be encouraged, by contracting out federal R&D programs, whenever this would increase the technological or innovative capacities of the companies concerned.

In essence, the Lamontagne Committee reasoned that private firms have a financial incentive to exploit the spin-offs from federally funded R&D which is absent in the case of employees of federal R&D establishments. Contracting-out would, in its view, increase the commercial pay-off from federally funded R&D.

In response to the recommendations of both the Science Council of Canada and the Senate Special Committee on Science Policy, the Make or Buy directive (later to be known as the Contracting-Out Policy) was enunciated in 1972.

1.2 Methodology and Organization

1.2.1 Analytical Framework

According to the Canadian "Make or Buy" policy of 1972, internal federal government R&D programs (called mission-oriented R&D programs) must be contracted out to industry whenever the technological or innovative capacities of the companies working in this area are likely to increase. While the primary purpose of federal R&D projects is to develop mission-oriented technologies and promote technological change in the public sector rather than the private sector, it was the view of policy makers that contracting out would, a) increase the likelihood that government funded innovative technologies be commercially adopted and, b) promote the development of Canadian industrial R&D capability. Contracting-out policy is then intended to meet government R&D requirements while at the same time generating additional benefits to the non-government sector through commercial exploitation of knowledge or technologies.

The major benefit from contracting-out is the gain arising from the greater commercial application of mission-oriented government R&D. Other benefits which accrue to the contractor include: the learning of new scientific and technical skills; the potential contribution to subsequent R&D projects; a more complete utilization of industrial research facilities and personnel; and lastly, assistance in discerning new opportunities for the commercial exploitation of its technological base.

In assessing the desirability of the contracting-out policy, it is imperative to ask under which circumstances the contracting-out of government mandated research is socially beneficial. This will depend not only on the difference in benefits, but also on the administrative costs of the program i.e. difference in cost of administering internal program versus contracting-out. More specifically, the net social benefit of contracting-out can be defined as the difference between net benefit of contracting out and net benefit of internal research.

Net Social Benefits (NSB) = Net Benefit from contracting out (NBC) - Net Benefit from in-house research (NBG).

where a) $NBG = P_g(1 + \alpha_g)GB - R(g) - C(g)$,

GB = value to the government of this particular research result

P_g = probability that government research will be successful in providing GB

α_g = proportion of GB arising as a commercial spin-off from government in-house research

$R(g)$ = resource cost of government research

$C(g)$ = cost of administering internal R&D

and where b) $NBC = P_c(1 + \alpha_c + \alpha_I + \alpha_A)GB - R(c) - C(c)$

P_C = probability that contractor will be successful in providing GB

α_C = proportion of GB arising as an internal commercial spin-off to the contractor

α_I = proportion of GB arising as an external spin-off to industry at large

α_A = proportion of GB received by the government beyond what is contractually required in order to increase the contractor's probability of receiving future contracts

$R(c)$ = resource cost for the contractor undertaking government research

$C(c)$ = cost of administering extramural research and other related contracting costs

Therefore,

$$NSB = NBC - NBG$$

$$= P_C (1 + \alpha_C + \alpha_I + \alpha_A) GB - R(c) - C(c)$$

$$- P_G (1 + \alpha_G) GB + R(g) + C(g)$$

$$= [P_C (1 + \alpha_C + \alpha_I + \alpha_A) - P_G (1 + \alpha_G)] GB$$

$$+ [R(g) - R(c)] + [C(g) - C(c)] \quad (1)$$

Letting $P_C = P_G = 1$ then,

$$NSB = [(\alpha_C + \alpha_I + \alpha_A) - \alpha_G] GB + [R(g) - R(c)] + [C(g) - C(c)] \quad (2)$$

Or alternatively, it can be written as

$$[\alpha_C + \alpha_I + \alpha_A - \alpha_G] GB - [R(c) + C(c) - (R(g) + C(g))]$$

In simple terms, contracting out is beneficial if the additional spin-off benefits generated by external rather than intramural R&D exceeds the cost difference of doing research in-house rather than contracting-out.

Since the above criterion is met only in some cases, it is clear that the general broad policy to contract out all R&D is misguided, and that the benefit to society can be increased only when a subset of appropriately determined R&D projects are contracted out.

1.2.2. Scope, Purpose and Outline of the Study

In the previous section it is shown that the advantage of contracting-out is determined by the following factors: (1) the net difference in spin-off benefits generated under contract as compared with those generated under internal research; (2) the difference in resource costs of conducting R&D intramurally and contracting out; and (3) the difference in the cost of administering an internal program versus contracting out.

To effectively administer the contracting-out program, policy makers and contracting officers must be able to identify ex ante the kinds of research projects that can be performed efficiently by private contractors. This requires knowledge of the magnitudes of the different types of economic spin-offs associated with either a specific project or type of project undertaken either inside or outside of the government. Similarly, decision makers must know which types of projects are more costly (in both resource and administration terms) to contract out. If program administrators possessed the relevant information, they would have a basis for determining which R&D projects have a greater likelihood of generating net social benefits when contracted out. However, the required information has not been collected in Canada or elsewhere. In general, very little is known about the factors influencing the benefits and costs of contracting-out.

In this study, we begin to fill in some of these gaps by exploring a subset of issues associated with government R&D contracting out policy. Rather than presenting a comprehensive analysis of this subject or providing a complete set of administrative guidelines for policy makers, our purpose is to provide greater empirical insight into certain key components of policy problems relating to R&D contracts.

The study is designed to take advantage of a wealth of primary micro data that has been collected, but not as yet used. With this unique data set, important information about different terms in the net social benefit equation from contracting-out can be derived. The nature of this data set, however, is such that it illuminates some but not all of the terms, and even with those it illuminates there is a limited amount that can be derived. Nevertheless, it permits a number of interesting questions to be addressed quantitatively for the first time.

Data was collected on R&D contracts, R&D contractors, and R&D contract outcomes from various sources. First, forty five sample R&D contracts from Transport Canada were examined in detail. Data on the nature of R&D work, the contractual structure, methods of remuneration, means of administering the R&D work and the disposition of rights to new discoveries was compiled. For each individual contract, a number of quantitative variables were constructed.

Data on contracting-out outcomes was obtained from survey questionnaires and follow up interviews with the contractors and government project officers. Firm specific information (size, employment, age, R&D expenditures, etc.) was collected from the contractors. In addition, contractors were asked to indicate both whether or not there had been economic spin-offs and the nature of these spin-offs. The project officers who were

responsible for each contract were asked to identify the direct and/or indirect benefits derived by the government. This shed new light on the outcomes of R&D contracts, both from the contractors' and government's view point.

The third source of data was the Statistics Canada, Science and Technology Statistics data bank. An extensive amount of information was collected and additional quantitative variables were created. The data bank provides additional information that was not obtainable from the contractor survey. All of the information collected is confidential and can only be accessed indirectly through the data base manager of the Science and Technology Statistics division.

Other data sources were various statistical series published by Statistics Canada and the Annual Indexes of the Canadian Patent Office Record, published by the department of Consumer and Corporate Affairs. The data gathering process and the description of the data bank are discussed in more detail in the following chapter.

The empirical exercise reveals that many new econometric techniques for dealing with qualitative variables can be profitably applied to the analysis of R&D contracts. An important contribution of this study will be to illustrate not only the applicability of such quantitative techniques, but also the scope of the measurement and data problems that will be encountered by researchers working in this area.

Each chapter of this study addresses a component of the net social benefit from contracting-out equation:

$$NSB = [(a_c + a_i + a_A) - a_g]GB + [R(g) - R(c)] + [C(g) - C(c)]$$

where the variables are defined as above.

The analysis begins in chapter 2 by addressing a subject of considerable attention in the economic literature - the costs of alternative contractual arrangements. In relation to Contracting-out or Canada's Make or Buy policy, the relevant comparison is the government cost of contracting for research externally relative to the cost of doing it internally, $C(g)-C(c)$. The study suggests reasons for believing that transaction costs (monitoring and enforcement costs) will be higher when the research is contracted out. The actual R&D contracting practices of a Canadian government department highlight some of the difficulties involved in the R&D procurement process and those observations are combined with theory to offer an economic rationale for the observed institutional design. The chapter also serves to highlight the type of information that researchers could expect to find from the contracts and related R&D documents. While the data set provides significant qualitative information on various cost aspects of the contracting-out process, it is unable to provide quantitative measures of the costs (monitoring and enforcement) of contracting-out relative to doing that research in-house. Nevertheless, the study reveals that in many circumstances, contracting costs are certainly not trivial.

The remaining chapters deal with other components of the net benefit equation. Chapter 3 deals with the R&D resource cost of contracting-out. Chapters 4 and 5 look at spin off benefits, and Chapter 6 deals with the government benefits component.

In addition to transaction costs, the desirability of contracting-out is affected by the cost of R&D resources absorbed by the contracts relative to intramural research, $R(g)-R(c)$. The true cost to a contractor of using one of its scientists on a government contract is the value of the research

the scientist would have produced on the best alternate project. If there is no alternate project and the scientist would have remained unutilized, the opportunity cost would be zero. In order to assess quantitatively the true resource cost, substantial information which is presently unavailable would be required. Instead, Chapter 3 provides an empirical analysis of the circumstances in which a government R&D contract is likely to utilize idle R&D factors, that is, factors with low opportunity costs. The analysis also indicates the situations in which a research contract is less likely to crowd-out self-financed R&D.

There has been a lengthy debate concerning the existence and magnitude of secondary benefits from government R&D contracts. The issue of technological "fall-out" or "spin-off benefits" has received attention in the theoretical literature, however empirical evidence on spin-offs has been inconclusive and often contradictory. The relevant question for the formulation of an appropriate contracting-out policy is not merely whether secondary benefits exist, but how large they are relative to both the cost of contracting-out and the secondary benefits that would have been realized had the research involved been done intramurally. Chapters 4 and 5 contain an analysis of the incidence of commercial spin-off benefits from government R&D contracts.

Chapter 4 examines the nature of the economic spin-off arising from a sample of Transport Canada's R&D contracts, and isolate empirically the circumstances where commercial spin-offs (α_c) are most likely to occur. An ideal measure of commercial benefits would be the discounted value of additional profits generated as a result of undertaking government financed R&D. Measures such as this are currently unavailable and are likely to

remain so for the indefinite future. The measure of spin-off benefits used in this study was obtained from a survey of contractors and government project officers conducted by the author. The survey is described in Chapter 2. Respondents were asked whether the contract with which they were involved yielded results which were commercialized. A "yes" answer would indicate the existence of economic spillover benefits while a "no" would imply none. Given that the data is limited to this qualitative measure, the focus of Chapter 4 is to estimate the statistical relationship between the incidence of economic spin-offs and: the terms of the R&D contract; various characteristics of the firm; and characteristics of the R&D work itself. This yields a profile of both the characteristics of firms that have been successful in generating secondary benefits and the contractual terms that contribute to the realization of economic spin-offs.

A policy variable which has received substantial attention is the assignment of property rights over technologies generated under contract. Chapter 4 addresses the question of whether the realization of commercial benefits from government R&D contacts depends upon the ownership of the property right. Empirical evidence supports the contention that the probability of a spin-off benefit is significantly larger when the contractor has the right to exploit commercially technologies developed under contract.

Chapter 5 takes into account the simultaneous relationship between the likelihood of commercial spin-offs and the vesting of property rights with the contractor. The incentive to innovate and commercialize depends in part upon the appropriability of research results. Conversely, the decision to negotiate for property rights is dependent upon the anticipation of spin-off benefits. The problem must therefore be examined in the frame-

work of a jointly-determined relationship. Wu's test for the endogeneity of a regressor indicates that a simultaneous equations estimation is appropriate. Heckman and MaCurdy's (1985) and Maddala and Lee's (1976) methods of estimation are subsequently employed. Estimates of the model as specified indicate that there is a significant positive relationship between the incidence of commercial spin-offs and the allocation of property rights to the contractors. The implication is that a contractor would negotiate for ownership when commercial spin-offs are expected. Presumably other contract terms are made more attractive to the government in return.

In Chapter 6 the trade-off between the realization of commercial benefits and the achievement of government research objectives is examined. It is found that the realization of commercial benefits comes at the cost of a reduced likelihood of meeting government research objectives.

Chapter 7 summarizes the major findings of this study. Substantial analyses remain to be done before one can understand and appreciate fully the effects of the Canadian Make-or-Buy policy. Some of the possible avenues for future research are discussed in this chapter.

Chapter 2

Contracting-Out Process

2.0 Introduction

As discussed in chapter 1, contracting-out leads to net allocative gains if the spillover benefit of having private contractors perform government research projects outweighs the costs of contracting-out. This suggests that both the nature of the contracting costs and the implications of the private incentives provided by different contractual mechanisms should be better understood before the contracting-out of R&D is encouraged. Given that the contracting-out is to be encouraged, we should better understand the types of provisions that could be incorporated into R&D contracts. This chapter furthers our understanding of these issues by providing a detailed description of the government R&D acquisition process, and an extensive examination of the practice of contracting-out as undertaken by Transport Canada.

The rationale behind the private provision of public technology is that the knowledge produced by the development of that technology is placed in the hands of those who have a financial incentive to exploit it commercially. Self-interest motivates the search for spillovers. Government employees have no incentive to look for commercial applications, however, they also have less incentive to mislead those who have commissioned the research or to engage in other types of opportunistic behaviour. The issue of whether a particular research and development project can be undertaken more efficiently by a private firm under contract, or by an internal government agency, is essentially a matter of how well the contract can solve this problem of diverging incentives.

Given that a government agency has decided to contract out an R&D project, what is the most efficient means of procuring that technology from a private firm? In general, the contractual arrangement adopted should be one that protects each party from the hazards of opportunism. That contractual arrangement encourages the mode of transacting that maximizes joint trading gains in part by preventing the individual parties from trying to redistribute the potential gains from trade. In some cases, a comprehensive contingent claims contract that specifies the obligations and responsibilities of both the government and the contractor will reduce the cost of the R&D project. In other cases, adaptive sequential contracting or other contractual relationships will be preferred.

Williamson (1979) has suggested three dimensions that describe characteristics of transactions that are of special importance: (1) the frequency with which the transaction recurs; (2) the degree of uncertainty; and (3) the degree to which durable transaction-specific investments are incurred. Of these three, Williamson stated that the degree to which the transaction involves idiosyncratic or specialized investments is probably the most critical dimension¹. The discussion of contracting-out in this chapter is carried out in the context of these transaction-cost dimensions.

Using a carefully constructed sample of Transport Canada R&D contracts, the study describes the various methods of awarding R&D contracts and the means of remuneration. A rough indication of the magnitude of administration costs is provided by a case study of a specific R&D contract. This chapter also provides a basic description of the types of contracts and the data base that will be used throughout the following study.

The chapter is divided into a number of sections. The first section defines mission-oriented R&D, explains what is the Make-or-Buy decision, and provides a discussion of the extent to which the federal government has contracted-out R&D. Section 2 provides a detailed description of the data bank employed in this study. Sections 3 and 4 examine, respectively, contract awarding mechanisms and contractual provisions which govern the transaction.

2.1 Policy Description and the Value of R&D Contracts to Industry

2.1.1 Mission-Oriented Research and Development

Each government department has a series of responsibilities assigned to it by the political process. To meet these delegated responsibilities or mandates, scientific and technical research is often required. When research is undertaken for the purpose of providing the scientific and technical knowledge required to fulfill these government mandates, the research is referred to as mandated or mission-oriented R&D. Mission-oriented R&D is not primary research. Rather, as defined by the Treasury Board, mission-oriented R&D is "research and experimental development minus free basic research plus feasibility studies."

The mission-oriented research of a department may vary from simple, standardized projects to a highly complex sequence of projects, each of which may be defined loosely or in precise detail. A project may vary in the degree of uncertainty and in the scientific and technical resources required. It may have a very short time horizon or require many years of research work. A project may necessitate substantial new and specialized capital commitments by the government or may involve the incremental

modification of existing technology and capital. In order to maintain control, technical and financial evaluations from the inception stage to the final stage are fundamental. The Administrative cost of maintaining effective control thus depends upon the nature of the project and the method by which the R&D work is being carried out.

2.1.2 The Make-or-Buy Decision

Having chosen its research objectives and secured funding, a government agency must decide how the research should be carried out. There are fundamentally two ways of undertaking federal mission oriented R&D - intramurally or extramurally. Intramural research refers to research that is being done by government scientists and engineers within its own laboratories. Extramural research refers to research work that is contracted out to industry, universities or non-profit organizations. In these terms the Make-or-Buy decision refers to the decision by the government agency either to Make (through intramural research) or Buy (through contracting-out to industry) mission-oriented R&D.

According to the Treasury Board Guidelines (1977), a project should be contracted out to industry whenever possible. The following conditions define the only possible exceptions:

"(a) where a question of security or policy sensitivity preclude private sector involvement.

(b) where the conduct of science and technology is essential to establish and maintain a limited in-house competence sufficient:

- to enable the department to perform its mission,
- to assess the opportunities represented by the current state-of-the-art, and
- to manage its science and technology requirements being performed in the private sector;

(c) where the science and technology capability needed to perform the mission of the department is inappropriate to the private sector, or does not exist in the private sector...

(d) where the science and technology capability is essential to provide direct support to a regulatory function and associated planning activities, and no private establishment independent of the individuals and organizations being regulated can be found or created (e.g., certain aspects of research associated with food quality, narcotics control and transportation safety regulations, communications);

(e) when the science and technology capability is essential to the development and maintenance of a set of national primary standards and, in some cases, secondary and consumer standards, including their relationship to international standards;

(f) where the conduct of science and technology is necessary to the effective support and operation of in-house capital facilities which provide federal testing and research services that are agreed, after appropriate consultation, to be necessary to Canadian industry."

In effect, the Make-or-Buy directive means that all mission-oriented research and development work is to be contracted out unless there is a clear justification for the government itself doing it.

2.1.3 The Value of Federal R&D Contracts to Industry

In 1984 the Federal government undertook total R&D expenditures in the Natural Sciences of over \$3.2 billion, of which approximately \$616.3 million (or 19 percent) involved payments to Canadian industry. Of that total, R&D contracts accounted for about 43 percent (or \$224 million). Over the period 1972-73 to 1984-85, the value of R&D contracts has grown dramatically. As illustrated in Table 2.1, nominal R&D contracts grew from under \$30 million to over \$200 million, an increase of over 700 percent, while in 1971 dollars the increase was 189 percent.

Table 2.1

Values of Federal R&D Contracts in Current and Constant Dollars

<u>Year</u>	<u>Current dollars</u> <u>(\$000,000)</u>	<u>GNE Implicit</u> <u>Price Index</u>	<u>Constant 1971 dollars</u> <u>(\$000,000)</u>
1972	27.2	105.0	25.9
1973	34.6	114.6	30.20
1974	35.4	132.1	26.80
1975	50.3	146.3	34.38
1976	69.2	160.3	43.17
1977	85.9	172.3	49.85
1978	101.4	183.8	55.17
1979	98.1	202.7	48.40
1980	100.2	225.2	44.49
1981	126.8	249.7	50.78
1982	144.8	275.5	52.55
1983	183.4	290.5	63.13
1984	224.0	299.3	74.84

Source: Statistics Canada: *Federal Government Expenditures on Activities in the Natural Sciences 1963-64 to 1984-85 Cat. No. ISSN 0821-1647; and Standard Industrial R&D Tables 1963-1982, Cat. No. 5582-3; and Resources for Research and Development in Canada, 1983, Cat. No. 88-2303.

While total R&D contracting-out has grown rapidly, the performance has not been uniform across all government departments. The major departments and agencies for which the Make or Buy directive applies include: Agriculture; Communications; Energy, Mines and Resources; Environment; Fisheries and Oceans; National Defence; National Health and Welfare; and Transportation. The amount of R&D contracted - out to Canadian industry by six major R&D performing departments is reported below (Table 2.2).

Table 2.2.

R&D Contracted out to Canadian Industry by Department

Department	<u>Current Dollars</u> ((\$000,000))			
	1981	1982	1983	1984
Communications	10.3	14.9	15.8	16.5
Energy, Mines and Resources	6.8	12.3	18.5	16.3
Environment	13.4	13.1	10.3	6.2
Fisheries and Oceans	5.4	3.6	6.0	6.5
National Defence	30.1	38.9	48.1	82.5
Transportation	8.7	11.9	17.0	16.9

Source: Statistics Canada: Federal Government Expenditures on Activities in the Natural Sciences 1963-64 to 1984-85, Cat. No. ISSN 0821-1647.

The absolute numbers hide the relative importance of contracting-out as an important R&D option for the different departments. Moreover they hide the extent to which the Make-or-Buy directive has been successful in increasing private involvement in government's R&D efforts. Table 2.3 indicates the proportion of R&D contracted to industry in natural sciences for the same departments.

Table 2.3

Payments to Industry as a Proportion of
Total Current R&D in Natural Sciences

Department	<u>Year</u>			
	1963	1972	1980	1984
Communications	0	58	34.9	21.16
Energy, Mines and Resources	0.3	9.5	7.5	6.81
Environment (including Fisheries and Oceans)	0	1.4	12.36	5.48
National Defence	20.7	20.9	33.1	46.45
Transportation	0	19.9	33.1	47

Source: Bhanich Supapol and McPetridge (1982), Economic Council of Canada Discussion Paper, Table II; and Statistics Canada: Federal Government Expenditures on Activities in the Natural Sciences 1963-64 & 1984-85, Cat. No. ISSN 0821-1647.

As Table 2.3 illustrates, Transport Canada has had by far the largest annual increase in the proportion of R&D contracted out to Canadian industry, and this proportion is expected to continue to rise.⁴ It then appears that Transport Canada has made conscientious efforts to increase private involvement in their research program and thus respond to the intent of the Make-or-Buy directive. For this reason, Transport Canada provides a good candidate for further analysis. Figure 2.1 provides an overview of recent Transport Canada experience by portraying the annual values of contracts to Canadian industry from Transport Canada between 1972 to 1984, in both current and constant dollars.

Figure 2.1

Transport Canada R&D Contracts to Industry

2.2 Sample R&D Contracts: The Data Bank

Studies of R&D contracting-out have generally been concerned with the relationship between public R&D support and private R&D investment at an aggregate level. Some have involved anecdotal analyses of cases where R&D contracting-out has been either a success or a failure at the industry level. Few studies, however, have attempted to examine the issue of contracting out at the project or contract level. An examination of each R&D contract and its related documents can be very instructive. A great deal of information regarding the nature of the research work, the various features of the transacting mechanisms, and the outcome of the project from the government's view point can be obtained. In addition, the contracts can provide information about the contractors and the specific researchers involved in each project. Moreover by analyzing many individual contracts similarities may be seen. This means that generalizations made from this procedure will be more robust than generalizing from particular episodes that may or may not be representative. In this study, we examine in detail the individual R&D contracts awarded by Transport Canada.

The purpose of this section is to outline the process by which contract information used in this study was collected. The primary sources of quantitative information used to analyze contracting-out in Transport Canada are: a survey of Transport Canada R&D contracts conducted in 1984-85; Statistics Canada - Science and Technology division data bank; and the Annual Indexes of the Canadian Patent Office Record, a Department of Consumer and Corporate Affairs publication.

Federal Science Expenditure data indicates that Transport Canada contracted out 83.1 million-dollars of Natural Sciences R&D to Canadian industry over the years 1975-1984, of which 45.8 million dollars (56 percent) was spent in the last three years alone. In 1975, Transport Canada contracted out 12 percent of its total expenditures in natural sciences R&D while in 1984, 47 percent was contracted out to Canadian industry. The increase is striking especially when compared to intramural R&D which remained relatively constant over the same period.

Research and development activities of Transport Canada are organized under four administrations:

- Departmental Administration
- Air Transportation Administration
- Marine Transportation Administration
- Surface Transportation Administration

According to data gathered from Federal Science Expenditures and Personnel 1977-1982, the total amount contracted out by Transport Canada to Canadian Industry was 48.2 million dollars. Approximately 60 percent of this amount was awarded by the Departmental Administration, through the Transport Development Centre in Montreal. The Marine, Air and Surface Administrations contracted out directly 30%, 7% and 3% respectively to account for the remaining 40%.

The first task in the data gathering process involved the selection of an appropriate sample of R&D contracts. Given the cost and time involved in retrieving the contracts and all related documents it was hoped that a sample of 45 contracts could be examined. Ideally, the number of R&D contracts selected from each program should reflect their respective proportions in total Transport Canada extramural R&D spending. Therefore,

in accordance with the distribution of expenditures, 27 completed R&D contracts were to be drawn from the Transport Development Centre, 13 from the Marine Transportation Administration, 3 from the Air Transportation Administration and the remaining 2 from the Surface Transportation Administration. However, cooperation from Marine Transportation Administration R&D officials was not forthcoming and no contracts from that administration could be examined.

Given that Marine Administration R&D contracts were excluded from the sample, the distribution of R&D expenditures was recalculated. In the absence of Marine administration R&D spending, 85.5% of the total available extramural R&D contracted to Canadian industry was accounted for by TDC, and 9.8% and 4.7% by the Air and Surface Administrations respectively. Accordingly, 38 contracts were drawn from TDC, 4 from the Air Administration, and 3 from the Surface Administration. To ensure that there was sufficient documentation and that success or failure was possible, two contract criteria were imposed:

1. Contract size greater than 100,000 dollars.
2. Contracts must have been completed by 1983.

Transport Development Centre R&D activities are divided into 4 general categories: Air, Marine, Rail and Surface. Out of 38 contracts from Transport Development Centre, 7 were selected from Air, 14 from Marine, 6 from Rail and 11 from Surface.

Once the sample contracts were selected, a questionnaire was sent out to the contractors. The questionnaire was split into two sections covering background information about the responding contractor and the R&D-contract results (see Appendix 1). A different questionnaire was also distributed to government scientific officers in charge of the same

R&D contract (see Appendix 2). These questionnaires were supplemented by follow-up interviews with private scientific managers and government project officers. Private sector respondents were assured that their answers would be completely confidential. In order to reinforce the importance attached to the survey, a letter from Transport Canada accompanied each questionnaire.

The actual distribution of contracts examined differed somewhat from that suggested by the initial plan. First, only one Surface Administration contract satisfied the contract criteria. Second, although three Air Transportation Administration contracts were examined, no firm specific information was possible as the contractors had since gone out of business. The balance of the contracts examined were, therefore, drawn from Transport Development Centre. This amounted to 41 contracts with the following distribution: Marine, 13; Rail/Surface, 18; Air, 11. In some cases, the contracts were not completed until 1984.

While 42 contracts (41 from TDC and 1 from Surface) are included in cross tabulations, other contracts let under the same project were also examined, bringing the total number of contracts examined to 46. Not all contractors responded to the questionnaire completely so that the number of contracts used in the regression analysis varied from 39 to 41, depending upon the set of exogeneous variables included. The list of contracts and contract titles are presented in Appendix 3. The information gathered from these completed questionnaires and interviews formed the principal data base for the study.

In order to examine additional hypotheses surrounding the contracting-out decision, additional information on the characteristics of the contractors was collected. The additional data came from four sources:

(1) Contracts and related documentation; (2) Annual Indexes of the Canadian Patent Office Record; (3) Statistics Canada and the Ministry of State for Science and Technology R&D Publications; and (4) Statistics Canada Confidential Science and Technology Data Bank.

There were a number of problems which made the data compilation process particularly demanding. First, the information from the Statistics Canada Science and Technology data bank was confidential. Indirect access to such information was possible through the help of Statistics Canada (Science Data Base: Science and Technology Division, Statistics Canada). This did mean, however, that the raw data required for the construction of some critical variables remained unobservable. Second, the econometric techniques required for the study are relatively new and have not as yet been incorporated into the econometric packages available to Statistics Canada. Consequently, the range of estimation techniques employed is somewhat narrower when confidential data are involved.

2.3 Mechanisms for Awarding of Contracts

There are basically three ways in which a company can receive a government R&D contract. First, the company can obtain a government R&D contract by competitive bidding. Bids can be submitted by any contractor and the choice is made by the government officials on the basis of the quality of the proposed technology, the reliability of the contractor and the bid price. The department is not required to accept the lowest bid. The second method is sole source negotiation. In this case, the government contracting officer selects the most suitable contractor and proceeds to negotiate the contract content and price with that company. The third method is through an unsolicited proposal contract. Here a project

is proposed by the contractor with some relevance to the departmental R&D program. Successful proposals may be sponsored by one or more interested government departments.

Table 2.4 indicates the distribution of the R&D contracts under examination by type of award mechanism.

Table 2.4

Distribution of Selected Transport Canada Contracts by
Type of Award Mechanism

Type of Award Mechanism

Competitive Bidding (CB)	10%
Sole Source Contract (SS)	43%
Unsolicited Proposal (UP)	47%

Source: Transport Canada R&D contracts selected for this study.

Alternative tendering processes incur costs of different kinds. Competitive bidding may be costly for some types of research work while sole sourcing may be costly for others. The dominance of sole sourcing over competitive bidding as observed by the sample may be explained at least in part by the nature of the research work involved and the costs of organizing competitive bidding in this environment.

2.3.1 Competitive Bidding

When a project is to be contracted out through competitive tendering, the sponsoring department asks the Department of Supply and Services (DSS) to advertise the project in the DSS bulletin. This is the most general means of communicating with potential contractors. In some cases, however, invited firms are drawn from a source list maintained by DSS. The choice between using public tender and inviting specific firms to

submit a proposal is made by the department and involves a trade-off that depends on the nature of the R&D work. The evaluation of R&D proposals is a costly process for the government, especially when the competition is multidimensional and not simply over price. Quality and speed of completion, among other things, are frequently important and these dimensions must be evaluated, compared and ranked across contracts. McAfee and McMillan (1985) cite a U.S. example where in one Air Force contract, government personnel used 182,000 man hours in evaluating the bids from four prospective contractors. On the other hand, limiting the number of bidders may reduce price competition and raise the ultimate price of the contract.

If the competitive selection procedure is followed, the sponsoring department, other interested departments and DSS may organize a briefing session for potential bidders to increase the responsiveness of contractor's proposals to departmental needs. This "bidders conference" is usually organized for more complex proposals. The principal purpose of the "bidders conference" is to ensure that all parties involved in the project understand thoroughly all the requirements and research obligations, thereby reducing the possibility of future misunderstanding and disputes.

Research proposals normally include a technical section outlining as precisely as possible the work to be done; a project schedule listing a specific time horizon for each research milestone; a section describing project administration, project control and management; per diem rates for each researcher involved, capital costs and an estimate of the total cost including a firm's fixed fee (profit); and names, qualifications, and experience of the staff and key research personnel to be assigned to the project.

Proposals vary substantially with the scope of work to be done, the value of the potential contract and the nature of the technology to be developed. For a large scale, long term project, a sequence of research contracts may be desirable. The government usually subdivides the project into several related phases, where successful completion of one phase is necessary before progressing to subsequent phases. Proposals for such projects normally provide information with respect to the technical content and expected costs of the current as well as subsequent phases.

Once the proposals from the interested companies are received by DSS, an interdepartmental meeting is set up to evaluate the bids. Government guidelines (Treasury Board Guidelines 1977) for R&D proposal evaluation state that proposals submitted by prospective contractors are to be analyzed in three stages. The first stage considers: the scientific or technical merit of the proposal; the contractor's capability to satisfy the requirements; the firm's financial capability; availability of equipment; need for assistance; past performance; and the relationship of the project to the firm's own long range plans. The second stage considers the price. The final stage considers other government objectives such as Canadian content and other industrial, regional and scientific strategies.

Currently, the Department of Supply and Services is authorized to award contracts for R&D work up to \$1,000,000 when at least two valid tenders have been received and the lowest tender has been accepted. For R&D projects of value \$500,000 or less, competitive proposals are not required. In addition to the above, a \$500,000 maximum ceiling is allowable in aggregate for contract amendments. R&D contracts with a value greater than \$1,000,000, require Treasury Board approval before the contract can be awarded.

Transport Canada's current practice of evaluating competing R&D proposals involves the following stages. After the procurement manager of the Department of Supply and Services has received all proposals, a team of government scientists and managers is appointed to evaluate and select the most suitable contractor or contractors (if parallel research programs are to be followed). This evaluation is typically done on the basis of a point rating system. Independent ratings done by each scientist/manager are then averaged to obtain a final score for each company, and the company receiving the highest score is awarded the contract. Unlike the procurement of standardized commodities where the lowest bid price wins the contract, the problem facing the committee is to choose an R&D proposal that not only has an acceptable price but also incorporates the most desirable package of attributes and has the highest probability of success. Once the proposal is selected the government proceeds to negotiate "fair and reasonable" costs.

Often technical and managerial aspects seem to take precedence over cost considerations. Consider, for example Transport Canada's competition for the development of an Intermediate Capacity Transit System. Proposals were received from five large transportation manufacturing companies, three of which were deemed capable of doing the work and were selected to proceed to the second stage.

Evaluation of proposals was done by criteria established in advanced and furnished to the bidders. The evaluation criteria and relative weights used are listed below:

1. Company or Consortium - 10%

- Competence with respect to project administration, system integration proven by experience
- Commitment in the field of urban transportation.
- Manufacturing capability.

2. Team and Management Structure - 30%

- Key personnel (relevant experience and qualifications).
- Project manager - relevant experience.
- Method of technology transfer from non-Canadian to Canadian participants and restrictions, if any, regarding Canadian exploitation of the knowledge acquired.
- Scheduling and cost control.

3. Understanding of Urban Transportation Matters - 20%

- Urban planning and systems analysis.
- Institutional factors and market place.

4. Technical Proposal - 25%

- Proposal approach, methodology.

5. Financial - 15%

- Canadian content.
- Potential spin-offs to transportation industry.
- Price (maximum cost, rates charged, profit level).

After the evaluation, the company that was rated best overall was awarded a contract for \$1,500,000. This was also the company that submitted the highest bid.

Another example is a research project that involved a remote sea ice thickness sensing device which was to be operated from a helicopter or a fixed wing aircraft. Thirty-two companies were invited to submit a proposal, and seven actually responded to the invitation. After evaluating the proposals, the project evaluation committee decided on the contractor who submitted the lowest bid price. It is interesting to note that by the time the project was completed, the actual cost exceeded the estimated cost by 44%. This suggests that in some cases, optimistic bid prices may result in substantial cost overruns for the government. The size of the overruns, however, are more likely to depend on the extent to which

contracts provide cost minimizing incentives rather than the bidding process. The relationship between cost and contractual form is discussed later in this chapter.

Transport Canada's contracting practices appear to be consistent with those used by the U.S. government. The U.S. government's acquisition of advance weapons normally concentrates on quality and delivery time rather than cost. Scherer (1964) states that

"...the value functions associated with advanced weapons programs are normally configured in such a way as to encourage quality increases and time reductions. When additional reliability or technical performance ...military decision makers are not inclined to pinch pennies. Second, cost predictions tend to be subject to much greater errors than quality and time predictions... As a result, military officials tend to discount cost predictions and give much greater weight to quality and time factors in competitions to select the contractor..." (p. 32)

These observations are also consistent with higher quality carrying a higher price tag. While Canadian government officials, like their American counterparts, seem to place greater emphasis on technical content and quality than on cost, the fact that the lowest bid doesn't always win the contract does not necessarily mean that price is less important than quality. It does appear, however, that in the majority of cases, the scientific capability/capacity and technical merits of the research team, as well as the qualification and experience of research personnel, are given substantial weight in the selection process.

Finally, past performance has an important effect on the selection process. While some tenders are publically advertised, others are by invitation only. A firm that has delivered poor quality or inferior work in the past may be excluded from the departmental "source list", thereby

losing the opportunity to submit proposals for future government contracts. A source list can be used to reward high quality and reliability and thus safeguard the government from the hazards of opportunistic companies who continue to submit overly optimistic proposals.

2.3.2 Sole Source Contracting

Consider next the sole source negotiated contracting alternative. Sole sourcing exists when a government department selects a contractor without a bidding competition, and then negotiates a mutually acceptable contract with this single producer. The sole-source contracting method is typically used only when one contractor is deemed capable of carrying out the required R&D, or when one company has a significant advantage over others because of the special skills, facilities, or technical knowledge acquired from previous research.

The advantage of sole-sourcing is that it permits the exploitation of scale and learning economies. McAfee and McMillan (1985) argue that "some economies can be achieved by having the same firm do the job each time: designs do not have to be redrawn, specialized skills do not have to be relearned, existing tooling can be reused etc." (p. 96)

The principal difficulty with sole sourcing is that a sole source contractor could use his position to drive up the contract price. This would be particularly true where a series of related contracts are involved. The firm that receives the initial contract will often be the only source for subsequent contracts. It has been argued that if the project involving a series of contracts had been tendered competitively at the beginning, then competition for the whole project would have kept

the price at the competitive level (McAfee & McMillan, 1985, p. 9.6). Indeed this may be the case if firms are required to give precise cost estimates for each successive stages that are individually enforceable. The enforceability of the whole contract depends in turn upon the nature and tightness of the actual contractual agreement and thus the hold-up possibilities once the project is in the process of completion.

Competitive selection provides no special advantage over noncompetitive selection when research objectives (technical content, design performance) cannot be easily specified and involve a high degree of uncertainty. For these types of research, contract amendments and cost adjustments are inevitable. This in turn, diminishes the importance of the initial cost estimate. These difficulties may explain why the government has relied largely on single source negotiation. In addition, sole source contracting must be employed in R&D projects requiring technology and/or information owned exclusively by the contractor. In this case the government must compensate the contractor for the use of patented technologies (or trade secrets). Frequently, this compensation takes the form of the government ceding the commercial rights to the contracted research results to the contractor.

While there are efficiency reasons why a government might want to restrict the invitation list, there are also instances where sole sourcing may be inefficient in a narrow economic sense but efficient in the broader political economic context. For instance, the contract may serve to protect domestic producers or to buy political resources (votes or help in campaigns) as well as R&D (Stegemann and Acheson, 1972).

2.3.3 Unsolicited Proposals

Unsolicited R&D proposals are R&D proposals that are initiated by the private sector. A government department may fund an unsolicited R&D proposal if it is compatible with departmental research objectives.⁷

Treasury Board Guidelines suggest two reasons for government financial support of unsolicited R&D projects: (i) to encourage industry to contribute to the accomplishment of government R&D goals; and, (ii) to increase departmental appreciation of Canadian industrial capabilities.⁸

To qualify for funding, an unsolicited proposal must meet the following criteria: (i) a project must engender the sponsorship of a department by supporting departmental mandates; (ii) the proposal must be judged by the sponsoring department to have scientific merit and to be technically feasible; and finally (iii) the proposal must be unique in either content or capability.⁹

Government control of costs (monitoring as well as production) is more difficult when the research is unique and requires special content or capability since no alternative suppliers are available to provide the research at a comparable cost. In addition, research proposals emanating from industry are likely to entail greater commercial interests. In order to enhance the likelihood of their being accepted, the company must structure its proposal to capture the attention of government scientists and R&D program managers. At the same time, the proposal cannot depart too far from its commercial orientation. There is then a potential tension between government and commercial objectives. This is the subject of further study in Chapter Six.

2.4 Contract Structure and the Governance of Research Performance

2.4.1 Specification of Obligations - The Work Statement

Perhaps the most crucial component of all R&D contracts examined is the contract "work statement". The work statement specifies as precisely as possible, the work to be performed, the exact methods to be followed and the process by which various stages of the R&D task are to be conducted. Technical dimensions and other scientific attributes, capital requirements, the testing environment, and quality standards are clearly stipulated where possible.

The work statement also specifies the delivery date as well as a schedule for the completion of various phases of the R&D project. In many of the projects considered in this study, there appears to have been considerable government pressure placed on the contractor to meet deadlines. However, there is seldom any contractual provision for explicit financial penalties for failing to meet prearranged completion dates written into the work statement.

2.4.2 Means of Reimbursement

(1) Types of Contracts - U.S. definitions

The three types of R&D contracts most often used in the United States are Cost-Plus-Fixed-Fee (CPFF), Firm Fixed-Price (FFP) and Incentive Fixed Price (IFP) contracts (Scherer, 1964; Danhoff, 1968; Murphy, 1971). Cost-Plus-Fixed-Fee contracts have traditionally been associated with R&D procurement, notably by the U.S. Department of Defense. CPFF provides for the reimbursement of all audited costs plus a fee, the amount of which is related to total estimated costs. For instance, a CPFF contract

may stipulate that the government will pay for R&D costs, estimated at 1 million dollars, plus a fixed fee to the contractor as profits or contribution to overhead costs of, say, 50,000 dollars. If actual R&D costs exceed the target R&D costs by \$30,000 dollars, the government is liable for the entire cost overrun, and the total cost to the government would be $\$1,000,000 + 50,000 + 30,000 = \$1,080,000$. The fee paid to the contractor would remain unchanged at \$50,000.

A Firm-Fixed-Price-Contract on the other hand, fixes the government's liability at the estimated cost plus fee, and the cost overruns (or underruns) are absorbed totally by the contracting firm. Using the above example, an FFP contract would leave the government's liability at \$1,050,000, while the contractor would absorb the \$30,000 overrun.

It has traditionally been argued that CPFF contracts provide the contractor with no incentives to minimize costs since cost overruns are borne totally by the government (Scherer, 1964, and McCall, 1967). An FFP contract, on the other hand, encourages the contractor to be cost efficient, but places on him all of the financial risk. This may not be efficient since the government may be able to bear risk at a lower cost.

The Incentive Fixed-Price contract shares the burden of cost overruns, providing cost efficiency incentives at the same time that it distributes the R&D risks. Under an IFP contract the deviation of actual from negotiated R&D costs is shared between the government and the contractor. The profit function for a firm performing R&D under this contract can be summarized as follows:

$$\pi = \alpha c^T + \beta (c^T - c^A)$$

where π = dollar profit on a single contract.

α = the fixed percentage of the estimated costs.

c^T = the estimated costs initially agreed upon.

β = the firm's sharing proportion of any cost overrun, $0 \leq \beta \leq 1$.

c^A = the actual total R&D costs.

Suppose that the sharing proportions β was 0.5 and as before, the cost overrun was \$30,000. With this arrangement, profits to the contractor would be \$35,000 ($50,000 - 0.5 (30,000)$) while total costs to the government would be \$1,065,000 ($1,000,000 + 50,000 + 0.5 (30,000)$). These contracts have received a great deal of attention in the literature (see, for example, McCall, 1967; Cummins, 1977; McMillan and McAfee, 1985).

(2) Types of Contracts - Canadian Definitions

Transport Canada has relied primarily on two types of contracts: (i) Cost reimbursement R&D contracts; and (ii) cost sharing R&D contracts. These two types of contracts can be classified roughly in the same category as the Firm Fixed Price contract discussed earlier. No Cost Plus Fixed Fee arrangement was observed, and only on one occasion did the government employ a contract similar to the Incentive Fixed Price.

Under a cost reimbursement contract, the government pays for all audited costs plus fee up to a maximum amount specified by the ceiling price. No cost overruns are allowed nor will there be reimbursement by the government without prior approval. Akin to Firm Fixed Price contracts, cost reimbursement with a ceiling does not reward failure, and appears to be an effective mechanism for ensuring the achievement of technical goals. However, there appears to be no incentive to deliver

the product below the estimated cost. Consider the previous example where the estimated R&D cost is \$1,000,000. If the actual R&D cost is \$800,000 the firm would be paid \$800,000 for the audited cost and the agreed fixed fee of \$50,000. The cost underrun of \$200,000 would be retained by the government. The contractor, has no incentive to deliver the R&D results for less than the estimated cost.

The second contractual form is the cost sharing contract. Here, the government shares with the firm, part of the R&D costs incurred in the process of conducting contracted R&D work. Suppose the government agreed to reimburse fifty percent of the R&D costs properly incurred, up to a maximum of \$500,000. This maximum "price ceiling" is the limit to which the government is financially liable. If project completion requires the contractor to spend \$1,020,000, the government would share the cost up to \$500,000 and the additional \$20,000 cost overrun would be borne by the contractor. As in the case of the cost reimbursable contract, there is no prior provision for contract amendment in the event of cost overruns. Thus, the cost sharing arrangement as currently employed by Transport Canada, provides cost-efficiency incentives for the contractor similar to those of the Firm Fixed Price contract.

Cost-sharing contracts are normally adopted when the government anticipates that commercial gains may be realized by the contractor, or when the contract complements the firm's own R&D program. For instance, in a program involving the design of an energy efficient aircraft, the government's share of costs in the initial stage was 85%, and in subsequent stages, where there was a higher probability of the information gained being of direct use to the company, the government's share was

reduced to 70% and then to 50%. In all cases the proportion of cost borne by the contractor is subject to negotiation.

According to some project officers, the role of cost sharing is to ensure that the contractor has a direct interest in the outcome of the project choice and screening process. It was hoped that this would lead to industrial exploitation rather than the mere delivery of final reports or prototypes. While this is possible, it is difficult to imagine how cost-sharing incentives in itself, will improve the chances of commercialization sufficiently if the government still retains the rights to the technologies developed under contract. If the benefits of commercialization are unappropriable, there is less incentive to pursue the development of government R&D results to their commercial stages. The interacting influence of property rights and cost-sharing rules on the development of commercial applicators of R&D is investigated in more detail in chapter 4.

In the sample of Transport Canada contracts examined in this study, industrial participation in the financing of R&D costs was encouraged when the firm retained the commercial rights to the technology developed. Commercial rights tended to remain in the hands of the contractor when the contractor used proprietary information or technology that it already owned. At the same time it appeared that the government does not finance all of R&D costs when information is owned by the contractor. The contractor then seemingly demonstrates his willingness to buy the rights through absorbing part of the R&D cost.

While incentive features are generally welcomed by economists, Incentive Fixed Price contracts have not been used extensively by

Transport Canada. Table 2.5 shows the distribution of payment modes in the sample of Transport Canada contracts.

Table 2.5

Distribution of Selected Contracts by Mode of Payment

<u>Mode of Payment</u>	<u>Percentage of Contracts</u>
Cost Reimbursement	68.3%
Cost Sharing	29.3%
Incentive Contract	2.4%

Source: Transport Canada R&D contracts selected for this study.

As the above table indicates, Transport Canada R&D contracts are predominantly of the cost reimbursable with a maximum price type while cost sharing with a maximum price accounts for a little less than one third of the sampled contracts.¹⁰

It might be argued that the use of a contract maximum leaves the contractor bearing most of the risk. However, from the sample contracts, it appears that the government amends contracts when realized costs are in excess of expectations and when this is not, in the opinion of the project officer, a consequence of contractor malfeasance.¹¹ The government's willingness to change the terms of the contract allows some reallocation of risk, but at the same time diminishes the usefulness of cost efficiency incentives associated with a fixed ceiling price. A flexible fixed ceiling results in an imprecisely specified contract, and the scope for contractual amendments leading to cost overruns is greater. McAfee and McMillan (1985) find that

"The advantage of the fixed price contract is the strong incentives it gives the contractor to minimize costs. This incentive effect can be lost if the contract specifications are not adequate, for two reasons. First, as already noted, if after a contractor is selected the nature of the work is seen to be different from that specified in the contract, the contractor has the right to renegotiate the contract. Once this situation is reached. Second, if the contract's specifications are vaguely worded, so that there is no precise criterion for the success or failure of the project, it may be impossible to establish that a contractor's work is of inadequate quality. In each of these cases of poorly specified contracts, the contract, while nominally fixed price, is essentially a cost plus contract in its incentives aspects." (p. 9.19)

Where research obligations are poorly specified, the agreement to reimburse R&D costs subject to a price ceiling is essentially a cost reimbursable (cost-plus) contract. The nominal price ceiling yields little effective restraint on cost. Therefore the cost of contracting-out can be expected to be higher in cases where the properties of the contracted technology and research directions are not well known. The problems posed by uncertainty of this type will be more severe the more advanced, relative to the state of the art, is the research. Similarly, the cost to the government will be higher in cases where the contractor has a significant information and/or technical advantage over the government. In both cases it is likely that a contract amendment will be required as research proceeds. This amendment will be more costly if by virtue of their specialized and irreversible commitments, the government and the R&D contractor would find it costly to turn to alternative suppliers and buyers respectively. Finally, there is a dynamic consequence to the government's willingness to amend contracts. In the absence of a willingness to hold contract terms, there is no penalty for business firms being increasingly optimistic regarding project cost.

Fees on the cost reimbursement contracts examined, have averaged from about 6 to 9 percent of estimated costs. Although fees are based on the projected cost, fixed fees are not adjusted when the ceiling price is amended.

Another provision which is common to all R&D contracts, is the hold-back of financial claims. The general policy is to holdback 20-25% of all claims. *In some cases the holdback may be reduced to 10% if the contractor can show good cause. This holdback is a performance bond. Upon successful completion of the project, government releases the hold-back without interest.

2.4.3 Disposition of Property Rights

(i) Property Rights to the Government (DSS 1036)

The general ownership and use of information, designs, inventions or prototypes developed under government funded contracts is governed by the contracting guideline DSS 1036, unless otherwise specified. Under this provision, all the results of contract R&D, incidental or otherwise are the property of the Crown and the government is not obliged to offer an exclusive license to the contractor.¹²

A rationale for the government's retention of property rights is that government may wish to secure benefits from competitive bidding on later stages of the project. That is, the government may not want to be "locked-into" a single source producer as a result of the fact the incumbent firm has exclusive rights to the information, manufacturing knowledge and engineering drawings, or the prototype. By retaining all rights it is possible for the government to turn to alternative contractors

without having to extensively duplicate the R&D work previously accomplished. The extent to which the government can turn to alternative suppliers depends of course on the degree to which information developed can be conveyed simply in manufacturing drawings and the ease with which specialized knowledge can be transferred across potentially competing firms (Scherer, 1964, pp. 114-116 and Monteverde and Teece, 1982). Another reason for the government's retention of property rights is related to the public good aspect typical of new information or knowledge. That is, once the idea is discovered or the technology is developed there is no reason for the government to exclude potential consumers.

(11) Property Rights to Contractor with Royalty-free license to the government

When a company makes use of its own prior discoveries in the performance of contract R&D, it requests that the government waive the rights to technologies developed under the contract and that exclusive rights to the use and/or manufacture any new products be assigned to the contractor. Typical statements included in such contracts are shown below:

"Title to the following shall vest in you:

- (a) all designs, technical reports, photographs, drawings, plans, specifications, models, patterns and samples;
- (b) all other property produced or acquired by you in any manner (other than Government issue not directly incorporated into this work) for the performance of the work;
- (c) all technical information, inventions, methods and processes conceived or developed or first actually reduced to practice in carrying out the contract."

and that

"You may file patent applications in respect of the above-mentioned inventions at your own expense and shall, subject to the following conditions, retain title to all such inventions:

- a) you shall grant to Her Majesty an irrevocable royalty-free license to manufacture and have manufactured in Canada and to use anywhere in the world, any article covered by such patents or embodying any such inventions:
- b) you shall grant to Her Majesty, if requested to do so, a non-exclusive license to use any relevant background patents owned or controlled by you upon payment by Her Majesty to you of reasonable compensation in respect thereof:
- c) if you elect ~~not~~ to file a patent application in respect of any invention arising under the contract, you shall, if requested by Her Majesty to do so, assign or cause to be assigned to Her Majesty all such rights as are necessary to enable Her Majesty to apply for a patent in respect of such invention."

However, even when the innovator receives the right to commercial applications, the government retains a non-exclusive license. That is, the government retains the right to access and use the information, design, patents and data obtained under the contract free of charge.

"You shall, upon the request of Her Majesty:

- a) disclose to Her Majesty all technical information, inventions, methods, processes and designs conceived or developed or first reduced to practice in the performance of the contract:
- b) make available to Her Majesty all designs, technical, reports, drawings, plans, specifications, models, photographs, patterns, samples and other materials and data arising out of or as a result of the carrying out of the contract:

- c) grant Her Majesty the royalty-free right to use, anywhere in the world, and the royalty-free right to disclose to allied Governments for informational purposes only, any or all of the designs, methods, processes, technical reports and other material and data mentioned in this article:
- d) grant full license to all or any of the designs, patents, property and data referred to Sub-section 1 above upon reasonable and non-discriminatory terms to any prospective licensees, including allied governments."

The government can further regulate the use of proprietary information with restrictive provisions such as:

"You shall not sell, assign, transfer or give to any person, company or partnership outside of Canada or to any government other than the Government of Canada, any rights to design, data or inventions arising out of the work, or sell, transfer or give to any person, company or partnership outside of Canada or to any government other than the Government of Canada, any license or other rights under any patents or applications for patents in respect of inventions or designs arising out of the work or permit the performance of the work or any part thereof or the manufacture of production of any product resulting from the work to be carried out outside of Canada, without obtaining the prior written consent of the Executive Director of the Transportation Development Centre of Transport Canada."

Some contracts may also include a provision for sharing the value discovery between the contractor and the government. This permits the government to recoup some of the research costs where profits are realized. For example, one of the contracts in the sample stipulates that

"...In the event that the contractor sells any models or prototypes, then fifty percent (50%) of the gross proceeds of the sale shall be paid to Her Majesty in a manner to be specified by Her Majesty."

and ...

"The Minister of Transport may direct the Contractor to pay to Her Majesty a portion of such profits, excess profits or royalties, or all of these, as may be derived from the use by the contractor of the technology developed under this agreement. This obligation to repay Her Majesty shall cease when the contractor shall have repaid the entire contribution of Her Majesty."

Under what circumstances would a contractor be interested in acquiring commercial rights? There is presumably little incentive for a firm to negotiate for the exclusive right to R&D results when it does not anticipate R&D outcomes to be of commercial value. On the other hand, when commercial benefits are likely, the contractor will try to acquire the property right (or exclusive licenses) to the R&D results, perhaps making other concessions to do so.

In the sample of R&D contracts investigated in this report, the general DSS 1036 provision appeared to reduce the incentive to explore for commercial potential. The project officers in charge of the sample R&D contracts indicated that in their opinion, DSS 1036 constituted a barrier to commercialization in 46.5 percent of the cases and that it had not in 53.5 percent of the cases.

What is the incidence of post contractual disputes over proprietary rights covering the R&D results? It is interesting that only in one case was there a discussion of the right to patent the innovation developed under contract. DSS 1036 applied to this contract. Approximately seven months after the initiation of the project the president of the contracting company wrote to the project officer advising him that

"...Under the terms of (the contract)...the Patent will belong to the Crown. The usual procedure, where time is not of the essence, would have the CPDL (Canadian Patent and Development Limited) make the application for and take out the Patent(s) covering the invention....

The invention will be assigned by the inventor to (the company), who will in turn assign to the Crown under the Terms of the Contract, should the Crown so require."

Apparently, the contractor had already applied for a patent and was willing to transfer the rights to the Crown, if "the Crown so required." After having consulted DSS and legal experts of CPDL, Transport Development Centre decided that the company was to assign the rights to the invention directly to CPDL, and that the company would thereafter obtain an exclusive license for the invention for a limited period. This seems to suggest that there is a cost to getting exclusive commercial rights and that the government is not giving it away. A firm may choose to keep the property right but it must buy it through absorbing part of R&D costs or give up other benefits of equal value.

Table 2.6 shows the incidence of the alternative dispositions of property rights in the Transport Canada sample used in this study.

Table 2.6

Distribution of Alternative Property Right Disposition

<u>In the Sample</u>	<u>Percentage of Contracts</u>
Entire Property Right With Government	67.5%
Some Property Right With the Contractor	32.5%

Source: Transport Canada R&D contracts selected for this study.

It is interesting that the government kept the rights to the innovation in the case discussed above, and in about two-thirds of the contracts examined, even though it is not in the business of producing the product. Government retention of property rights may be desirable in cases where the incumbent firm is in a position to behave opportunistically in subsequent procurements, because of its first-contractor advantages. The DSS 1036 provision reduces the degree to which the government is committed to a specific contractor, and thereby the degree to which the government is exposed to opportunistic recontracting.¹¹

From our discussion one would predict that DSS 1036 would perversely influence the commercialization of contract R&D. Since even by-product innovations are the property of the Crown, there is less incentive to explore their potential than would be the case if DSS 1036 applied only to the results specifically contracted for, or if contractors were given exclusive rights to all innovations. Therefore, commercialization is expected where DSS 1036 does not apply. However, it is possible that the relationship between commercialization and ownership of property rights is a simultaneous one where the ownership decision itself is endogeneous. That is, if the commercial right has a high value to the firm, then the firm would buy it. This does not mean, however, that conferring ownership to the firm necessarily increases efficiency, even when commercialization is increased. The affect of property right assignment on commercialization is investigated in a multivariate context in chapters 4 and 5.

2.4.4 Monitoring: Its Institutional Form and Costs

Once the contract is signed, the project management function is one of maintaining the flow of technical and financial information so that

the sponsoring department can ensure that the contractor adheres to his contractual obligations. Management responsibility for smaller R&D contracts is assigned normally to a project officer in the sponsoring department. He acts as both the scientific authority and the co-manager of the contract with the procurement manager of DSS.

For large R&D projects, a significant amount of attention from a large number of specialists and administrators may be required to monitor a contractor's performance. In these cases responsibility for monitoring larger and more complex R&D projects is delegated to a steering committee. Supervision is necessary to ensure that discrepancies between promised and actual performance are not due to contractor negligence. In addition, the steering committee must recommend the appropriate method of dealing with such situations.

How costly is it to manage an R&D contract? What is the extent to which specialists in the project steering committee are employed? How extensive are their monitoring functions? These are some of the pertinent questions which must be considered in order to shed some light on the cost of contracting out R&D projects. However, these are not easy questions to answer.

While theoretical circumstances when the use of market exchange (through arm's length contractual agreements) is costly relative to non-market alternatives have been examined by Alchian and Demsetz (1972), McManus (1975), Williamson (1975, 1979), Cummins (1977) and others, little empirical evidence has been forthcoming. This is due in part to the fact that contracting costs are both project and relation specific. That is, the contracting cost depends on the nature of the work to be performed as well as on the identity and relationship between exchange parties. For

research and development, the cost of monitoring and measuring performance will be lower when the research objective is to produce a specific technology, the success of which can be determined by measurement or inspection. For instance, research required to produce a new high intensity light source can be deemed not to have been successfully-completed if the lamp will not come on, or if it does not meet the level of brightness contractually specified.

At the other extreme is experimental research. Were the tests which the contractors claimed to perform actually performed? Were they performed as described? The validity of experimental results cannot be determined simply by reading them. Their validity can be determined by replication or by inspection and supervision both of which are costly.

Project evaluation, managing and monitoring project progression, and enforcing contractual provisions can be very expensive functions for the government. In personal interviews with government officials involved in R&D contracting, it was indicated that the costs of contracting averaged 7% of the value of the project.¹⁴ For some projects, however, contracting costs are substantially higher, as is shown in the case cited below.

In order to monitor the contractor, periodic meetings of the project steering committee and firm's representatives are organized. During these meetings, the contractor describes the progress of the project and indicates problems encountered and potential problems that may arise. The committee then evaluates the firm's effort and/or costs, as well as the R&D results to date. Necessary changes in the course of research or objectives are proposed and discussed at the steering committee meetings. To provide an example of the magnitude of the management effort required to administer an R&D project, consider the particulars of one specific

R&D contract awarded by TDC to a private manufacturing firm to work on a train location, identification and control system. Members of the steering committee for this project included 3 individuals from Transport Canada, 1 from the National Research Council (NRC), 9 experts from the railway industry, 1 U.S. representative associated with an American railway, and 3 representatives from the company, including the president of the company. At least three committee meetings were organized, one of which involved an on-site visit to Vancouver. Evaluating the time of these specialists at the senior-engineer fee (\$22.00 per hour) and transportation costs of half of the committee members (\$1,000 per meeting), the cost of the steering committee alone is about \$36,000, or approximately 19.5% of the total project cost.¹³ This figure was well above the 7% average cited above. One reason why the administrative costs were so high in this case was that this contract represented the initial contract of an on-going multi-stage program. Moreover, this particular contract involved a consortium of several companies and cooperation between these firms was managed by the steering committee. Follow-on projects would have required less monitoring once a working relationship between the government and the contractor had been established.

Another way to evaluate a contract's performance is through the use of monthly progress reports. Firms are generally required to submit a monthly report outlining their progress, costs to date, problems and difficulties encountered and expected in the future, and estimates of the cost of solving these problems. Submission of these reports allows the government to monitor and control the direction of research.¹⁴ It appears that a monthly progress report requirement is standard on all R&D contracts.

As one would expect, reliance on a steering committee to manage the project is less prevalent in contracts where there was a provision for the modification of DSS 1036. There is less need to enforce greater diligence when R&D has commercial possibilities and the contractor stands to benefit from the completion of the project and the exploitation of these possibilities.

2.4.5 Dispute Resolution

Given the uncertainty associated with research and development work, government R&D contracts are naturally incomplete, and disputes of various kinds inevitably arise. There are a number of ways in which conflicts can be resolved. The government and the firm commissioned to do the work may negotiate an amendment to the contract, or may use an arbitrator. Alternatively, the government or contractor may use the court of law to resolve their disputes (litigation). A final alternative is the termination of the contract.

Although R&D contracts are legal agreements and litigation is possible under contract law, it seems that a less formal approach to resolving disputes is generally preferred. None of the 45 Transport Canada contracts examined in this study involved any litigation. Only one contract termination was observed. It is generally in the mutual interest of the government and the contractor to prevent such breakdowns. Contractual breakdowns can be costly especially for research requiring specialized and irreversible commitments.¹⁷

Almost all of the contracts observed were amended to some extent. In most cases two or more sets of amendments were necessary. Two cases are examined here. In the first case, the dispute was finally resolved

by contract termination. In the second it took the form of a number of contractual amendments.

In the first case, an R&D contract to construct and field demonstrate an experimental prototype of a navigation device was awarded to a new and small research firm. Nine months later the contract was amended to cover additional costs which were "beyond the control" of the contractor. The amendment allowed for a cost increase of 20.7%, and the delivery date extended by 3 months (18%). Two months later the contractor informed the government that he had diverted his work force to other projects because his invoice had not been paid. The contractor said that project delays would result if there were more delays in paying invoices and preparing a contract amendment. During this time no progress reports were submitted.

Following these events, a series of telexes were received informing the government of technical problems, schedule slippage and additional cost overruns. A year and a half later, the steering committee conducted an on-site inspection and met with the contractor. Only one of the six major tasks which were supposed to have been completed had been completed acceptably. A new delivery schedule was agreed upon and the contractor promised to allocate his total effort to the project. After some time, it was determined that none of the items promised for delivery were available. Furthermore, the contractor was often out of town working on another project and could not be contacted by TDC.

The project officer recommended that DSS renegotiate the contract with this company to subcontract some of the remaining work to other contractors. In his opinion,

"The company is now one year late in its delivery schedule, and appears to lack the expertise necessary to complete the work."

In an interdepartmental note from the procurement manager to the scientific authority, it was stated that financial claims (above and beyond the 20.7%) for work not approved by the department would not be funded. The president of the company in turn replied that he did not intend to deliver the final report pending the resolution of his further claims. The DSS procurement manager communicated to the Scientific Authority that:

"As it appears that this question of (the company's) further claims will not be resolved expeditiously could you please evaluate the deliverables you have received against that information you might additionally expect to get in the final report. The value of the final report should then be measured against the holdback of _____. The reason for this evaluation is that (the contractor) may eventually take the position that he is prepared to forego the holdback for an amendment to the contract which does not require the final report delivery."

It stated further that:

"The bottom line to resolve this contract may well be referral of the (company's) claims to our Contract Settlement Board or the Crown may sue (the company) for delivery of the final report and/or (the company) may sue the Crown for additional money."

Department of Supply and Services and the company eventually came to an agreement for the contract settlement. It was agreed that the company would not deliver the final report to the government and that financial holdback would not be released. An understanding that DSS would prepare necessary contract amendment to terminate the contract was reached.

Another contractual problem frequently encountered is schedule slippages and other delays as a result of reassignment of researchers and

R&D facilities to other higher priority projects. Consider for instance, a contract to carry out a study on a high efficiency gas turbine. A large R&D intensive manufacturing firm with significant experience in turbine engines was awarded the contract. At the time the contract was signed, the company was involved in a number of commercial projects with significant market potential. The company had submitted a bid for a large commercial project, and if successful, the firm would be obliged to use the entire staff on the project. Following the agreement with the government, the Science Procurement Manager was made aware of this possibility. It was recognized that as a result of this reassignment of R&D inputs, the original project milestones could not be met. A number of alternative options were identified in order to complete the project. Termination of the contract was also identified as one of the options.

It was agreed that the company would continue the research work provided that additional staff with acceptable knowledge and experience could be hired. Recognizing the departmental need for the successful completion of the project, the procurement manager was urged not to become "high handed or naively rigid" in the course of conducting the meeting with the company.

However, after two years, the schedule slippage problem had not been alleviated and alternative courses of action were considered. According to a project officer, further delays were unavoidable "unless something is done to persuade the company that the project should be given higher priority". Following a series of negotiations between government senior officials and a senior executive of the company, it was decided that the remainder of the project should be completed by subcontracting to another firm.

Evidence of the government procurement process indicates a general reluctance on the part of the government to terminate a contract, even after repeated contractor's failure to perform. This predisposition to amend contracts reflects the high cost of turning to an alternative supplier. The cost of transferring the R&D work to a more cooperative contractor will be higher in cases where specialized physical investments or specific non-patentable know-how (acquired through performance of the contract) are involved (Monteverde and Teece, 1982). Although in all R&D contracts, it was clearly stipulated that the government retains ownership to specialized physical assets, rents will still occur unless such assets can be relocated at low cost. The existence of firm specific know-how and expertise implies that it will be costly for the government to turn to an alternative contractor.

2.5 Conclusion

Transport Canada's contracting-out experience indicates that contracts were most often awarded on the basis of a single source negotiation rather than a competitive bidding process. In cases where research objectives cannot be clearly specified and are subject to significant uncertainty, the contract is likely to be renegotiated as the research proceeds. As a consequence, competitive selection can offer the government little idea as to the true cost of research and, as such, provides no special advantage over non-competitive selection. Inefficiencies associated with R&D contract competition encourage the government to rely on relational type contracting processes where the identity and reputation of the contractor are important. Sole sourcing to a contractor with proven capabilities and performance records can then reduce contracting

costs by rewarding performance and avoiding the costly process of evaluating competing bids.

Cost reimbursable and cost-sharing contracts with a maximum price are the predominant forms of contract used by Transport Canada. R&D contracts are not contingent contracts and provide no prior provision for contract amendments in the event of cost overruns or project delays. They do not reward failure and appear to be effective mechanisms for ensuring the achievement of technical goals. However, from the examination of Transport Canada's experience, it was observed that the government often renegotiates amendments to the contracts. Where the required research to be performed is poorly specified and is subject to a variety of possible outcomes, the scope for post-contractual renegotiations and, thereby, the contracting cost, will be larger.

In two-thirds of the cases, the government retained ownership to the technology conceived under contract and, in the remaining one-third the contractor was awarded the property rights with the government as a non-exclusive licensee. The latter is typically the case where the company's own proprietary technologies or specific know-how (trade secrets) were required for research purposes. Of course, a contractor may in some situations choose to forego the benefits from exclusive commercial rights, provided that he is adequately compensated. Compensation may be in the form of a higher contract price/profit, promises of future contracts, or more favourable contractual terms.

From a particular case study, the magnitude of the management cost required to administer an R&D project to successful completion was found to be almost 20% of the total project cost. While this does not provide a precise estimate of the administrative burden nor an average contrac-

ting cost, it does indicate that in some circumstances, the administrative costs associated with R&D contracting-out can be significant.

Evidence from the analysis of two other cases shows the length that the government is willing to go before they will terminate a contract. From all the contracts examined, only in one case did the government terminate a contract and go elsewhere. Perhaps this reflects the degree to which irreversible commitments have been made in the procurement of research. If specific investment has been made and it is costly to go elsewhere, the government is thereby more exposed to contractors' opportunistic behaviours and contracting costs will be higher. Willingness to renegotiate a contract in itself is desirable if it can be verified that the circumstances have changed and that these changes are not the fault of the contractor. Adaptive (or sequential) renegotiations allow both the government and the contractor to economize on the cost of contracting. However if a contract renegotiation is a result of the "hold up" problem, contract amendments can be costly.

This chapter provides further insights into the cost of contracting-out R&D, and suggests circumstances where the procurement of research is expected to be costly. Whether contracting-out itself is desirable depends on the relative cost of administering contract versus internal R&D. Future surveys might usefully ask whether the research could have been performed in-house and, if so, how much of the project officer's time and the project steering committee's time would have been devoted to the research project.

A number of interesting hypotheses related to contracting theory might also be tested by regressing the contracting cost and the internal administrative cost against some of the contract and contractor discriminating characteristics.

ENDNOTES

1. Other who emphasize the costs associated with transaction specific investment include Klein, Crawford and Alchian (1978), and Klein (1983). The specific type of contracting problems that arise in relation to R&D have been discussed by number of authors. These include Scherer and Peck (1963), Danhoff (1968), Goldberg (1976, 1977), Globerman (1980), Caves, Crookell and Killing (1983), Armour and Teece (1980), Davidson and McPettridge (1984), Masten (1985) and others.
2. Treasury Board, Administrative Policy Branch, Guidelines for the Implementation of the Make-or-Buy Policy Concerning Research and Development Requirements in The Natural Sciences; Administrative Policy Branch (1977), Policy and Guidelines on Contracting-out the Government's Requirements in Science and Technology.
3. Treasury Board (1977), Policy and Guidelines on Contracting-out of the Government's Requirements in Science and Technology, p.5
4. Bhanich Supapol A. and McPettridge D.G. (1982), "An Analysis of the Make-or-Buy Policy", Economic Council of Canada, Discussion Paper 217 (Ottawa: Economic Council of Canada).
5. The selection is based upon the distribution of the value of completed R&D contracts of each mode, aggregated over the relevant period. Over the years 1981-1983, \$18,772,122 was spent in support of industrial R&D (adjusting for university and other non-profit institutions), of which \$3,215,717; \$6,815,594; \$3,130,704 and \$5,550,037 were contracted under each mode respectively. A list of contracts awarded by Transport Development Centre specifying contract title, price and duration for each of the four modes of transportation was provided by Transport Canada R&D officials. Similar information could be obtained from Transport Development Centre Annual Project Directory.
6. This is guided by the costing memorandum DSS1031.
7. If a proposal is approved but cannot be funded from the sponsoring department's current appropriation, the Unsolicited Proposal Fund can be used to support the project. The sponsoring department can then arrange to reimburse the DSS managed Unsolicited Proposal Fund See Ministry of State for Science and Technology Canada (1982), Federal Government Incentives for Industrial R&D.
8. Treasury Board, Administrative Branch (1977), Policy and Guidelines on Contracting-Out the Government's Requirements in Science and Technology, p.9
9. Ibid

10. In the single incentive contract in the sample, cost reimbursement was combined with a maximum ceiling price. In addition, the following contractual incentive provision was included for the fare:

"a fee to be augmented by way of bonus to the fixed fee equal to 25% of the amount by which labour cost is less than 86,492 provided that in no event shall the total profit consisting of fixed fee and bonus exceed 12 1/2% of the actual labour expended"

11. The ability to assign responsibility for any failure to meet research objectives depends upon the extent to which the contract can clearly specify research obligations. See Williamson (1975).
12. Patent assignment procedures are governed by Treasury Board Minute 468904 of August 18, 1954; of which an extract is presented below.

COMMITTEE ON DISPOSITION OF PATENT RIGHTS
IN RESEARCH AND DEVELOPMENT CONTRACTS -
EXTRACT FROM TREASURY BOARD MINUTE NO.
468,904 OF 18 AUGUST 1954

The committee makes the following recommendations:

- (1) That patent rights arising out of Crown-financed research and development contracts continue, as a matter of policy, to be vested in the Crown;
- (2) That the following principles govern the disposition of Crown-held patent rights:
 - (a) The public interest is best served when inventions become generally available through successful commercial production.
 - (b) Within Canada:
 - (i) Non-exclusive should be granted where practical; exclusive licenses only where there appears to be no other expedient way of exploiting a patent.
 - (ii) The Crown should normally attempt to recover the full overall costs of patent exploitation, but not development costs. To this end royalties should be calculated on the basis that when added to the cost of production the selling price will not deter the development and distribution to the public of such inventions.
 - (iii) Where exclusive licenses are granted, however, due consideration must be given in the fixing of royalties to the advantage granted the licensee as well as the benefit to the public in distribution of such development.

- (c) For exploitation outside Canada:
 - (i) Ordinary commercial principles should normally apply and appropriate royalty charges be made.
 - (ii) Under special circumstances, royalty-free licenses may be granted to governments of countries other than Canada.
- 3. That the administrative framework to handle Crown-owned patents be established as follows:
 - (a) Title to inventions should be retained by the departments or agencies concerned.
 - (b) Exploitation of patents should continue to be handled by Canadian Patents and Development Limited.
 - (c) In advising the Minister of National Defence, the Inter-departmental Advisory Committee should interpret policy so that the best interest of the taxpayers may be served in exceptional or borderline cases.
- 13. What is implicitly assumed here is that transaction cost is positive and the delineation of property rights to the government is a superior solution to the problem. From Coase's theorem we know that delineation doesn't matter if transaction cost is zero and wealth effect is ignored. However, because it is costly to monitor and measure precisely what the contractor is doing, and the government knows that it will get less if the contractor has the commercial rights, it may be desirable in some cases for the government to retain ownership.
- 14. According to the officials of the Department of Supply and Services, the average cost of administering extramural R&D contracts amounts to 7 percent of the value of the contract. According to Transport Development Center statistics, over \$932,000 was spent on the administration of approximately \$18.7 million of R&D contracts over the years 1981-83. This accounts for about 5 percent of the value of the contract on average.
- 15. Fees are based on the figures cited in the contract in question.
- 16. Firms are likely to pass on the cost of preparing monthly progress-report to the government.
- 17. Of course the extent to which research and development is continued depends on the cost. While it is normally beneficial to prevent contractual breakdowns, in some cases it may be more efficient for the government to terminate a contract and turn to an alternative contractor.

Chapter 3

The Determinants of the Opportunity Cost of Resources Devoted to Contract R&D

3.0 Introduction

Contracting-out government research to industrial firms may impose extensive demands on private scientific and technical factors. Some of these factors have alternative employment while others would have remained idle in the absence of a contract. An important consideration in the contracting-out decision is the relative cost of performing government R&D in-house as opposed to contracting-out, $R(g)-R(c)$. This implies that the value of the R&D resources utilized by the contracts in their best alternative employment is an important factor. Therefore, it is essential to first determine whether these resources would have been idle or fully utilized.

The purpose of this chapter is to examine the nature of R&D resources (idle or otherwise) absorbed by government R&D contracts, and investigate empirically the circumstances under which an R&D contract is more likely to employ resources that would otherwise have been idle. Under these circumstances, contracting-out is likely to be more advantageous, in terms of resource costs, than performing in-house R&D. By concentrating empirical work on the particular types of firms that are able to use government funded research to maintain a more complete utilization of R&D resources, the paper isolates and develops for policy makers a list of the characteristics of those firms that have been most successful in this regard.

The empirical analysis focuses directly on information gathered from the contractors about the use of R&D facilities and personnel. This data provides an opportunity to test the relationship between the probability of a contract utilizing idle resources and contractor characteristics.

Very little information about the opportunity cost of R&D resources used under contract is presently available. The little that is known is generally inferred indirectly from related studies involving the effects of government financed R&D on private R&D expenditures. While the literature devotes considerable attention to the possibility that government financed R&D may crowd-out self-financed R&D, only a few studies have investigated the means by which crowding-out could take place. There has, to date, been no empirical investigation of either the cause of crowding-out, or the circumstances under which it occurs.

The focus of this chapter is the determination of the circumstances under which resources for contract R&D are more likely to have been idle. Put another way, the analysis determines the circumstances under which contract R&D displaces or crowds-out privately financed R&D.

The next section develops a theoretical model of the relationship between contract and privately-financed R&D in the presence of congestion costs and commercial spillovers. The conditions necessary for crowding-out to occur are derived in this context.

3.1 A Model of A Firm Performing R&D

While contracts for R&D exert a direct effect on the sectoral distribution of R&D performance by shifting part of the federal R&D effort out of government laboratories into industrial research establishments, it is

not clear how or whether private research and development activities will be affected.

Some researchers have suggested that government R&D contracts crowd-out company-financed R&D (Carmichael, 1981; Higgins and Link, 1981; Lichtenberg, 1984, 1987, Longo, 1984). They argue that, in the short run, facilities available for R&D are limited and so R&D contracts may bid scarce R&D resources away from company financed R&D projects. Moreover, firms may receive government contracts for R&D projects that they would otherwise finance themselves, or information and technology developed by the firm and paid for by the government may allow the firm to forego some previously necessary research. That is, the contract is a substitute for R&D that the firm would have done. As a general point, if this is the case, contracts for R&D will contribute little towards increasing the level of private R&D.

Others (Goldberg, 1979; Scott, 1984; Link and Terlecky, 1983 and Mansfield and Switzer, 1984) believe that government R&D contracts stimulate private R&D expenditures. They argue that government R&D contracts may result in spillover knowledge or technologies which render private R&D activity more productive. Other indirect benefits may include suggesting new areas of research that the contractor might undertake, giving the contractor a head start on the next generation of technology which, in turn, may prompt contractors to expand their own R&D investment.

The model developed below illustrates analytically how government R&D contracts could stimulate or drive out private R&D investment.

Consider a firm which performs both internal R&D and contract R&D. The short run profit function from R&D activities can be represented as:

$$\Pi = V(R, C) - W(T, S)R - [M(T, S) - P]C.$$

<1>

The revenue function, $V(\cdot)$ is determined by R and C , where R is internal R&D, and C is contract (external) R&D. The revenue function represents revenues generated from products or processes, including royalty payments but excluding payments for contract R&D. Contract R&D, C , is sold externally for P per unit, and it is assumed that C produces spillovers which are captured in the revenue function. The model further assumes that $\frac{\partial V}{\partial R} > 0$, $\frac{\partial^2 V}{\partial R^2} < 0$ and that $\frac{\partial^2 V}{\partial R \partial C}$ can be either negative, positive or zero, depending on the nature of the contracted R&D.

The above cross-partial component is negative when the government and commercially oriented R&D of the firm are substitutes. That is, more government R&D implies a lower invention generating potential for commercial R&D. The cross-partial is positive when the two types of R&D activities are complementary. When there are no technological overlaps, the cross partial is zero.

The first scenario can arise if the government funds R&D work that the firm would have carried out anyway, or if for some reason, government R&D renders private R&D results obsolete, or less valuable.

The cost of doing R&D is divided into two components. The first is the cost related to internal R&D, $W(T, S)R$, and the second is the cost associated with contract R&D, $[M(T, S) - P]C$. $W(T, S)$ denotes the per unit cost of internal R&D and is assumed to be an increasing function of the total amount of R&D activity, T , as well as factor prices, S . Total R&D, T , is the sum of internal and contract R&D. That is $T = R + C$, and $dT = dR + dC$. The unit cost of internal R&D is formulated this way to demonstrate the effect of the short run R&D resource constraint, or resource congestion.

Similarly, the per unit cost of doing contract R&D is $M(T,S)$, and the effective cost to the firm is the difference between the actual resource cost and the contract price. As before, the inclusion of T as an argument in $M(\cdot)$ is meant to capture the effect of the R&D capacity constraint.

$$\text{Hence } \frac{\partial M}{\partial T}, \frac{\partial M}{\partial S} > 0 \text{ and } \frac{\partial^2 M}{\partial T^2}, \frac{\partial^2 M}{\partial S^2}, \frac{\partial^2 M}{\partial T \partial S} > 0.$$

The firm's objective is to maximize profits from R&D by choosing the optimal level of R and C . The first order conditions for a maximum are

$$\frac{\partial \Pi}{\partial R} = V_R - [W(T,S)' + W_{TR}] - [M_{TC}] = 0 \quad \langle 2 \rangle$$

$$\frac{\partial \Pi}{\partial C} = V_C - [W_{TR}] - [(M_{TC}) + (M(T,S) - P)] = 0 \quad \langle 3 \rangle$$

The profit maximizing firm will equate the marginal revenue generated from internal R&D to the additional costs, including congestion costs in R&D factors on both internal and external R&D activities. Similarly, the firm will equate, at the margin, revenues generated from spillover technologies as a result of performing R&D contracts to the marginal cost of contract R&D.

The second order condition requires that the matrix

$$\Delta = \begin{bmatrix} V_{RR} - (2W_T + W_{TT}R + M_{TT}C) & V_{RC} - (W_T + W_{TT}R + M_{TT}C + M_T) \\ V_{CR} - (W_{TT}R + W_T + M_{TT}C + M_T) & V_{CC} - (W_{TT}R + M_{TT}C + 2M_T) \end{bmatrix} \quad \langle 4 \rangle$$

have a positive determinant when evaluated at the optimal R^* and C^* . The respective effects of a change in the unit yield on contract R&D on internal and contract R&D are:

$$\frac{dR}{dP} = V_{RC} - (W_T + W_{TT}R + M_{TT}C + M_T) / |\Delta| \quad \langle 5 \rangle$$

$$\frac{dC}{dP} = -V_{RR} + (2W_T + W_{TT}R + M_{TT}C)/|\Delta| \quad (6)$$

Assuming that $W(\cdot)$ and $M(\cdot)$ are convex functions of both T and S , it is clear that $(W_T + W_{TT}R + M_{TT}C + M_T)$ and $(2W_T + W_{TT}R + M_{TT}C)$ are both positive.

Consider first the effect of a change in P on internal R&D. If contract R&D and internal R&D are substitutes, then V_{RC} is negative. Given that R&D contracts adversely affect the marginal revenue product of internal R&D, an increase in P will unambiguously decrease private R&D. This would also be the case when government-financed R&D has no effect on the value of the marginal product of private R&D ($V_{RC}=0$).

If contract R&D raises the value of privately-financed R&D, $V_{RC} > 0$: an increase in P will increase R , if $V_{RC} > W_T + W_{TT}R + M_{TT}C + M_T$. That is, private R&D will increase, if the contribution of government R&D contracts to private R&D productivity outweighs the increase in unit R&D costs. If the unit cost increase is larger than the contribution that government R&D contracts make to the profitability of the firm's own research and development, an increase in P reduces R . The unit cost increase is greater, the larger are R and C , that is, the closer the contractor is to full capacity utilization.

Consider now the effect of a change in the unit yield on contract R&D on the amount of contract R&D. We find from equation (6) that $\frac{dP}{dC} > 0$ provided $V(\cdot)$ is a continuous concave function in R and C .

The effect of a change in P on is:

$$\frac{dT}{dP} = (V_{RC} - V_{RR}) + (W_T - M_T) \quad \langle 7 \rangle$$

The net effect of P on T is ambiguous and depends on the sign and magnitude of V_{RC} , V_{RR} , W_T and M_T .

In the longer run, $W(\cdot)$ and $M(\cdot)$ need not be functions of T . If unit R&D costs are constant the long-run profit function can be written as:

$$\Pi = V(R, C) - W(S)R - [M(S) - P]C \quad \langle 8 \rangle$$

$W(S)$ represents the unit cost of internal R&D and is a continuous convex function of S . $W(S)$ is independent of T in the longer run. Similar arguments can be made for the unit cost of external R&D, $M(S)$. Making use of the second order conditions, the effects of a change in P on R and C respectively are:

$$\frac{dR}{dP} = \frac{V_{RC}}{V_{RR}V_{CC} - V_{RC}V_{CR}} > 0 \quad \langle 9 \rangle$$

$$\frac{dC}{dP} = \frac{-V_{RR}}{V_{RR}V_{CC} - V_{RC}V_{CR}} > 0 \quad \langle 10 \rangle$$

If contracts increase the profitability of private R&D then, as P increases, R will increase. On the other hand, if private and government financed R&D are substitutes, $V_{RC} < 0$, the opposite will be the case.

From equation (10), an increase in P will clearly increase C . The effect of a change in P on total R&D can be summarized as

$$\frac{dT}{dP} = \frac{dR}{dP} + \frac{dC}{dP} = \frac{V_{RC} - V_{RR}}{V_{RR}V_{CC} - V_{RC}V_{CR}} \quad \langle 11 \rangle$$

If $V_{RC} > 0$, in the long run there will be a net increase in total R&D as the unit yield on contract R&D increases.

If $V_{RC} < 0$ and $V_{RC} < V_{RR}$, then an increase in P will lower the total R&D activity of the contractor. This would occur when internal and contract R&D are strong substitutes, and the marginal productivity of R decreases faster with increases in C than R .

3.2 Review of the Literature

The issue of how government financed R&D affects private R&D was first investigated by Blank and Stigler (1957). The authors were interested in determining the influence of governmental research programs on the demand for engineers and scientists in research and development. Blank and Stigler (1957, pp. 57-58) argue that:

"At one extreme it might happen that private businesses first take on government research contracts, as a result become persuaded of the benefits of research, and then embark upon private research also - so that the government contracts serve a sort of pump-priming function. At the other extreme, research that the businesses had been conducting on their own account might simply be shifted to public contracts, so these contracts would constitute no net additional demand."

Blank and Stigler (1957) divided a sample of manufacturing firms into firms with and without government research support. For each firm the ratio of engineers and scientists engaged in private research to total employment was calculated. The authors argued that if this ratio is smaller for firms with government contracts, then public R&D efforts are being substituted for private research. Blank and Stigler found evidence of substitution in 15 of 17 industry groups. On average, they found that research personnel engaged in private R&D work account for 0.7 percent of total employment in

firms having government contracts, and 1.4 percent in firms engaging in purely private R&D. Since the engineers and scientists who worked on government contracts accounted for 0.8 percent of total employment in firms with government contracts, Blank and Stigler surmised that: "seven-eighths of professional employment on government research contracts represents a substitution of public for private research" (p. 59).

When they considered only those firms which engaged in both privately and publically-financed research, however, Blank and Stigler found that on average, industries with higher ratios of engineers and scientists in private research to total employment also had higher ratios of engineers and scientists engaged in government research to total employment. Having recognized that firms with large scale private research are more likely to obtain large government contracts, the authors stratified firms according to size and compared these ratios. They concluded that there is evidence of a complementary relationship between public and private research, and that the relationship appears to be stronger for larger firms. The authors wrote:

"We do not interpret this as strong evidence of a complementary ("pump-priming") relation of public and privately financed research, because the coverage of the largest firms is by no means complete. But the comparison does suggest strongly that the crude estimate of substitution derived from the aggregate data grossly exaggerates the forces making for a substitution relation" (p. 62).

Carmichael (1981) examined the effect of federal R&D expenditures on company expenditures by estimating the equation

$$C = \alpha + \beta_s S + \beta_g G,$$

where C and G denote measures of company and government R&D activity, respectively. S is the size of the firm (total sales of the firm). Employing

firm-level data for the U.S. transportation industry, Carmichael found significant statistical evidence of partial crowding-out. On the basis of regression estimates, he concluded that each dollar of government funding stimulates approximately 92 cents of total resources devoted to R&D, implying crowding-out of private research investment by 8 cents for every dollar of contract R&D ($\beta_g = -0.083$).¹

Lichtenberg (1984) argued that specifications such as Carmichael's do not hold all the determinants of interfirm differences in self-financed R&D constant. He further argued that since these omitted scale factors are positively correlated with contract income, β_g estimates are biased upwards. He suggested that rather than attempting to measure these omitted contractor characteristics, differences among contractors should be assumed constant overtime. The changes in self-financed R&D overtime could be attributed to changes in government contract income.

Estimating the following equation

$$\tilde{C} = \alpha_0 + \beta_0 \tilde{G},$$

$$\text{where } \tilde{C} = (C - C_{-1}) / (C_{-1} + G_{-1}) \text{ and } \tilde{G} = (G - G_{-1}) / (C_{-1} + G_{-1})$$

Lichtenberg found that for twelve U.S. manufacturing industries over the period 1963-79, there was not a significant relationship between company and government-funded R&D.² He also found that changes in contract R&D resulted in changes in current and future self-financed R&D with the sum of these effects being zero.

The above equations were then re-estimated with the employment of R&D scientists and engineers, rather than R&D expenditure, as a measure of R&D activity. The results led Lichtenberg to conclude that contract R&D had a

strong negative contemporaneous effect on company-financed R&D. Specifically, increasing employment on contract work by 100 scientists results in a reduction of 32 scientists employed in self-financed R&D.³

Finally, using firm-level data on R&D intensity (R&D expenditures as a fraction of total sales), and estimating the first-difference equation described above, Lichtenberg again found evidence of crowding-out.

While both Carmichael (1981) and Lichtenberg (1984) presented important evidence on the crowding-out issue, neither offered any insight into the mechanism by which private R&D is displaced by government contracts.⁴ The question remains as to whether the crowding-out is a case of government R&D substituting for R&D that the firm would have done anyway, or of government research bidding away limited resources from private research. The remaining sections of this chapter investigate the possibility of resource constraint crowding-out.

3.3 Evidence on the Nature of R&D Resources Employed on Transport Canada Contracts: General Statistics and a Multivariate Analysis

3.3.1 Evidence on the Opportunity Cost of R&D Resources Employed on Transport Canada Contracts

Transport Canada R&D contractors responding to the survey described in Chapter 2 were asked to identify whether the contract they had received had enabled them to make use of otherwise idle R&D inputs. A "yes" answer here would imply no crowding out while a "no" would imply capacity constraint crowding-out. Resources employed in R&D were divided into two categories, research personnel and research facilities. Based on the results of the survey, contractors indicated that idle research scientists and engineers were employed in 45 percent of the contracts awarded, and idle research facilities were utilized in 30 percent.

Over 77 percent of the cases involve either non-idle R&D facilities or non-idle R&D personnel. The implication is that in at least 77 percent of the cases, the contractor's R&D resources would have been employed in other R&D activities in the absence of the contract. The conclusion that there was some firm-specific or short-term crowding-out appears inescapable.

The next question is whether the incidence of idle factors being employed on a contract is random or varies systematically with the characteristics of the contractors. That is, is it possible to isolate statistically those contractors who are more likely to use resources which otherwise would have been idle on government R&D contracts?

A crosstabulation of contractor characteristics and the incidence of idle resource utilization is reported in Table 3.1. It indicates that idle scientists and engineers were employed on government contracts more frequently in manufacturing firms, whereas, idle facilities were more frequently employed in service firms. About half of the contractors with a manufacturing capability used idle resources of either kind on government contracts and 58% of R&D service firms employed some kind of idle resources.

The incidence of a contract employing idle resources appears to be greater for smaller (with sales less than ten million dollars in 1978) and newer (less than twenty years in business) firms. About 63 percent of the contracts awarded to Canadian-owned companies involved idle resources whereas merely 13% of the contracts going to foreign owned firms utilized resources which would otherwise have been idle. There is also evidence that contacts with firms employing more specialized R&D personnel (more than 10 percent of researchers holding a Ph.D. degree) made use of

Table 3.1

Contractor Characteristics and Idle Resources

Contractor Characteristics	Proportion of contracts (in %) which involved:		
	Idle R&D Personnel	Idle R&D Facilities	Idle Resources in General
1. Line of Business			
Manufacturing	25%	75%	50%
Service	42%	50%	58%
2. Contractor Size (Sales)			
Less than (or equal to) \$10,000,000	48%	62%	67%
More than \$10,000,000	11%	26%	37%
3. Age of the Firm			
Less than 20 years	54%	61%	69%
More than 20 years	19%	37%	44%
4. Ownership			
Foreign	0%	13%	13%
Domestic	38%	53%	62.5%
5. Specialization of Scientists and Engineers ^a			
Less than 10% of Researchers with a Ph.D.	16%	42%	45.2%
More than 10% of Researchers with a Ph.D.	87.3%	62.5%	87.5%
6. R&D Capital Intensity (Average Capital to Current Expenditures) ^a			
Less than 10	36.7%	46.6%	53.3%
More than 10	10.1%	62.5%	55.6%

Source: a) Science Data Base, Science and Technology Division, Statistics Canada.

idle resources more often than firms which are not as specialized. The cross-tabulation also seems to indicate that idle resources are used more often in firms with more capital intensive R&D operations.

While Table 3.1 demonstrates that the likelihood of a contract employing idle R&D factors can be related to contractor characteristics, some of the relationships observed may not hold up in a multivariate analysis. Therefore, a systematic investigation using multivariate regressions is undertaken.

3.3.2 Determinants of a Contract Employing Idle R&D Resources: A. Multivariate Analysis

Not all R&D firms with idle resources engage in government R&D contracts, and not all R&D firms which are actively performing R&D work for the government have idle resources at the time of the contract. There are four possibilities summarized in Table 3.2.

Table 3.2

Joint Probability Table: Contracts and Idle Resources

Contract with the Government (C)

	Contract with the Government (C)	
	<u>NO</u>	<u>YES</u>
Possess idle research facilities and/or personnel (I)	<u>NO</u> $(NI \cap NC)$	$(NI \cap C)$
	<u>YES</u> $(NC \cap I)$	$(I \cap C)$

Let $P(I \cap C)$ represent the probability that an R&D performing firm possesses idle resources and is performing contract R&D work on behalf of the government, and $P(NI \cap C)$ represent the probability that a firm is contracting with the government and is employing non-idle R&D resources.

Ideally, the empirical analysis would predict three of the four joint probabilities given in Table 3.2. Either multinomial logit or multiple discriminant analysis could be used. This would, of course, require observations on firms in all four boxes in Table 3.2. This study has access only to data on contracting firms. As a consequence the analytical problem becomes one of predicting either $P(I/C)$ or $P(NI/C)$. Since $P(I/C) P(C) = P(I \cap C) = P(C/I) P(I)$, predicting the probability of a contract having idle resources is equivalent to predicting the respective probabilities that a firm will have idle resources and, given that it has idle resources, that it will seek and obtain an R&D contract.

Moreover, if the determinants of the incidence of idle resources are uncorrelated with the determinants of the probability of obtaining a government contract, given idle resources, regression analysis of $P(I/C)$ which is observed, can be used to test hypotheses about $P(C/I)$, which is not observed.

Given that a firm has idle resources, under what circumstances would one expect to see it obtain an R&D contract? One approach to the problem is to start with the options available to a firm in periods of fluctuating demand for R&D factors. A firm faced with excess R&D capacity may respond by: (1) selling off redundant R&D assets and laying-off non-active scientists, engineers, and other technical personnel; (2) transferring these inactive R&D resources to other R&D projects and/or non-research operations

within the firm such as administration, management or production; and (3) employing these idle factors on government R&D contracts.

There are costs associated with each of these options. Presumably, one would not expect a firm to hire and fire research personnel or to sell-off and reacquire research facilities in response to temporary changes in capacity utilization.

Whether a firm chooses to allocate idle resources internally or chooses to employ idle R&D factors on government R&D contracts would depend upon the relative costs of finding suitable employment for idle factors within the firm and employing them on government contracts.

The dependent variable employed in this analysis is a dichotomous, variable taking the value one where the i th R&D contract involves scientific resources which otherwise would have been idle, and zero otherwise.

It should be noted, however, that there can be partial adjustments where some idle factors are employed on a contract and others are allocated to different tasks within the firm. In order to account for such a mixed response, ideally one would like to observe the proportion of idle factors employed on individual contracts. As responses to the survey are in an all-or-nothing rather than continuous form (see Chapter 2 for a description of the survey), the empirical work in this study necessarily concentrates on all or nothing type responses (i.e. whether or not idle resources are absorbed by the contracts). The task then is to extract the maximum amount of information from this kind of quantitative variable.

3.3.3 Explanatory Variables

(1) The Specialization of Research Personnel and Facilities

The objective of the firm is to manage idle scientific resources in the most cost-efficient way. Whether it finds allocation of technical per-

sonnel and scientific facilities to other non-research activities within the firm less costly than employing such factors on research and development projects commissioned by the government depends in part upon the nature and attributes of the idle factors. Presumably, if a firm's research and development assets are more job specific and more specialized, the firm will find that it is more efficient to have these factors employed on an R&D contract and allow them to work within areas of their comparative advantage. Because of their specialized nature, these factors face limited employment alternatives, and their lack of substitutability makes it relatively more costly for them to secure suitable non-research work within or outside the company. The greater the degree of specialization, the greater the cost disadvantage of adapting these inflexible assets to other uses.

Two measures of the degree of specialization of contract R&D operations are constructed. The first is the proportion of R&D personnel with a Ph.D. This is intended to reflect the degree of R&D personnel specialization. By the reasoning above, the greater the proportion of R&D personnel with a doctorate, the more likely it is that an R&D contract will be sought in order to employ them.

The second measure is the ratio of capital R&D expenditures to current self-financed R&D expenditures. If R&D equipment is more specialized than personnel, a firm with a more capital intensive R&D operation is more likely to seek government R&D contracts as a means of utilizing R&D resources than a firm with a less capital-intensive R&D operation.

Capital intensity is calculated by taking the mathematical average of the ratio of the firm's capital R&D expenditures to current R&D expenditures, over three years. A positive coefficient is expected for this variable.

(2) Variability in the Demand for R&D Services.

The greater the variability in the demand (or derived demand) for a firm's R&D services, the greater the probability of observing either deficient or idle capacity. Given the ability of the firm to economize on R&D inputs, the probability that a contract has idle R&D resources increases with the variability of the derived and direct demand for the contractor's R&D services.

We have no measure of the variability of the demand for R&D. We can measure the variability of the contractor's own expenditures on R&D. This depends on both the variability of demand and the success the contractor has had in employing R&D resources elsewhere in the firm or in government financed R&D projects. That is, a firm's own R&D expenditures may be more variable because of past successes in obtaining government contracts (a positive sign), or because of a greater ability to employ R&D resources elsewhere or lay them off (a negative sign).

To measure a firm's specific variability in non-government R&D demand, the standard deviation of self-financed R&D expenditures over the years for which data are available, divided by the mean value of the same reporting years, is calculated. Since the firms in the sample, report their R&D spending for different years, the effect of intertemporal biases is removed by dividing each firm's coefficient of variation, as calculated above by the corresponding industry's coefficient of variation, calculated for the same reporting time period. As argued above, the sign of this variable may be either positive or negative.

(3) Ratio of R&D Personnel to Total Employment

The smaller the proportion of total employment accounted for by R&D personnel, the less costly it will be to absorb these personnel into the other operations of the firm and the less likely the firm is to seek a government contract to employ them. For this reason, the probability that an R&D contract employs idle personnel should be an increasing function of the ratio of R&D personnel to the contractors total employment.

(4) Size, Ownership, Age, and Industry Effects

The more diversified a firm's markets and R&D activities, the greater the likelihood that a decrease in one line of research activity is counterbalanced by increases in others. Diversification thus reduces the cost of reallocating idle R&D resources within the firm. If diversification is associated with firm size, the probability that an R&D contract employs idle resources should be a decreasing function of firm size.

Multinational corporations are more diversified internationally and may also be more diversified locally than domestically owned firms. Therefore, foreign controlled/owned establishments should be better at reallocating R&D resources internally and will thus be less inclined to seek government contract in order to smooth out their R&D demand. As a proxy for multinational diversification, a foreign ownership dummy variable, taking the value one for foreign ownership and zero for domestic ownership, is used in the regression analysis. The expected sign of this variable is negative.

The third variable to be considered is the age of the contractor. It is recognized that technical and managerial competence are positively

related to the age of the firm (Mansfield, 1982). The ability to find alternate R&D or non-R&D employment within the firm may also be an increasing function of the age of the company. Older research organizations which have had more experience operating in an environment of uncertainty and fluctuating demand for R&D services may have a backlog of unfinished internal research projects for slack periods. Moreover, the research personnel of older corporations may be more experienced and diverse in their interests, and thus more capable of participating in different innovative activities.

The opposite effect is also possible. Experience in research may also make it less costly for an older firm to secure a government R&D contract than a newer, less experienced firm. The cost of both forms of adjustment may decline with age, and the relative cost may change in either direction. The age variable used in the empirical work presented here is the number of years between the year of incorporation and the contracting year.

The fourth variable is the line of business of the firm. To test whether the propensity to turn to government contracts in times of deficient R&D demand is the same for firms with and without manufacturing capability, a dummy variable, taking on a value of 1 for manufacturing firms, and zero otherwise, is included as an explanatory variable. The expectation is that a manufacturing firm has more options for the employment of idle R&D inputs, and therefore would be less inclined to seek contractual employment.

(5) Industrial R&D Cycle

Since the R&D projects in the sample were initiated at different times over the period 1975 to 1984, the analysis may be subject to the biases of

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differing industrial R&D climates at various points in time. To take into account the influence of cycles in industrial R&D, the empirical analysis explicitly incorporates the divergence between the actual demand for R&D in a given year and the anticipated demand based on a long-term trend of that same year, as a proxy for unanticipated upturns and downturns in demand. The likelihood of observing a contract utilizing idle resources should be greater for firms in industries experiencing a downturn in R&D demand, and lower for firms in industries experiencing expansions. By including the divergence between actual and trend R&D in the regression, the systematic influence of the industrial R&D cycle is held constant. This variable is calculated by taking the difference between actual aggregate industrial R&D spending, and the calculated time trend of R&D spending, based on a constant exponential growth rate. This variable is computed for the years contracts are initiated and for the industries to which the contracting firms belong. The expected sign is negative.

3.3.4 The Model of R&D Resource Utilization Determinants

The model can be summarized as

$$P_{ij} = f(RRPHD_j, CAP_j, RRND_j, CV_j, REV_{1j}, FOR_j, AGE_{j1}, MANF_j, IC_{1j})$$

where P_{ij} = Probability that the i^{th} contract absorbs R&D factors which otherwise would have remained idle

$RRPHD_j$ = proportion of R&D personnel with a Ph.D. to total R&D employment of the j^{th} firm

CAP_j = average ratio of capital R&D expenditures to current R&D expenditures if the j^{th} firm is calculated as

$$\left(\sum_{i=1}^3 \frac{\text{Capital}}{\text{Current}} \right) / 3$$

$RRND_j$ = the proportion of total R&D personnel to total employment of the j^{th} firm

CV_j = standardized coefficient of variation of the j^{th} firm, calculated by taking the coefficient of variation of self-financed R&D based on all reporting years and divided by the corresponding industry coefficient of variation

REV_{ij} = total revenue of the j^{th} firm in the year the i^{th} contract is awarded

FOR_j = 1 if the j^{th} firm is foreign owned

= 0 otherwise

$AGEC_{ij}$ = age of the j^{th} contracting firm defined as the number of years from incorporation to the year in which the i^{th} contract is awarded

$MANF_j$ = 1 if the j^{th} firm is a manufacturing firm (primary and secondary)

= 0 otherwise

IC_{ij} = industrial R&D spending relative to trend for the industry in which the j^{th} firm operates and the year in which the i^{th} contract is awarded.

3.3.5 Econometric Issues

The hypotheses advanced above are tested using linear probability analysis. A dichotomous dependent variable takes on the value 1 in the

event that the contract goes to a firm with idle R&D facilities or personnel, and zero otherwise. In the usual regression framework, the probability that the event occurs can be written as

$$E(y_1) = P(y_1 = 1) = F(\tilde{X} \tilde{\beta})$$

where $\tilde{X}$ is a matrix of nonstochastic regressors, and $\tilde{\beta}$ is a vector of unknown parameters. A functional form that is frequently used is the linear function

$$F(\tilde{X} \tilde{\beta}) = \sum_{j=1}^k \beta_j X_j + \beta_0$$

Econometric complications posed by dependent variables that are restricted to a subset of the real line, such as a zero-one variable, have been addressed by Amemiya (1981), Goldberger (1964), Maddala (1983), McFadden (1976) and others. Two major difficulties when the probability model is specified in this fashion have been pointed out. The first difficulty is that the residual variance is not a constant (heteroskedasticity). This, in turn, causes the usual significance test (t-test) to be invalid. Another difficulty is that the probability estimates may not lie within the 0 and 1 interval.

Goldberger (1964) suggests a 2-step procedure to correct for the heteroskedasticity problem. The procedure consists of estimating first the OLS regression, and then computing $y_1(1 - y_1)$ and using weighted least squares. Defining the covariance matrix Ω with diagonal elements $y_1(1 - y_1)$, the GLS estimates can be obtained by the formula below.

$$\hat{\beta}_{GLS} = (X' \Omega^{-1} X)^{-1} X' \Omega^{-1} y$$

One practical difficulty with this method is that y is not constrained to lie between 0 and 1, and thus some of the diagonal elements in the covariance matrix may be negative.

Given this difficulty, Halbert White (1980) introduced an alternative method which deals with heteroskedastic residuals in general. White discussed a method for performing a significance test in the presence of heteroskedasticity which does not involve the process of actually weighting each observation.

It can be shown that least squares estimator

$\hat{\beta} = (X'X)^{-1} X'y$ has expectation β and covariance matrix $(X'X)^{-1} X' \Phi X (X'X)^{-1}$, and under the general assumptions (certain boundedness requirements must be satisfied):

$$\sqrt{T} (\hat{\beta} - \beta) \sim N(0, Q^{-1} V Q^{-1})$$

where $Q^{-1} = \lim_{T \rightarrow \infty} \frac{1}{T} X'X$ and $V = \lim_{T \rightarrow \infty} \frac{1}{T} X' \Phi X$, where T is the total number of observations.

The above relationships can be used to perform hypothesis tests, provided that the consistent estimator V is obtainable.

White demonstrated that a consistent covariance matrix estimator with heteroskedastic errors can be determined without defining specifically the structure of the heteroskedasticity. The proposed method is discussed below:

For a linear model

$$Y_i = X_i \beta + u_i,$$

where $(X_1 u_1)$ is a sequence of an independent but not necessarily identical distributed random vector, such that $E(X_1' u_1) = 0$. Making additional assumptions concerning boundedness of error variances, the average covariance matrix regressors, and the singularity of the average covariance matrix of regressors, White showed that

$$\sqrt{T} \bar{V}_T^{-1/2} \bar{M}_T (\hat{\beta}_T - \beta_0) \xrightarrow{d} N(0, I_K)$$

$$\text{or } \sqrt{T} (\hat{\beta}_T - \beta_0) \sim N(0, \bar{M}_T^{-1} \bar{V}_T \bar{M}_T^{-1})$$

$$\text{where } \bar{M}_T = \frac{1}{T} \sum_{i=1}^T E(X_1 Y) \text{ and } \bar{V} = \frac{1}{T} \sum_{i=1}^T E(\epsilon_1^2 X_1' X_1)$$

Ω is the $n \times n$ diagonal matrix with diagonal elements $\sigma_1^2 = E(u_1^2)$. If X matrix is nonstochastic

$$\bar{M}_T = \frac{1}{T} (X'X) \text{ and } \bar{V}_T = (X'\Omega X) \frac{1}{T}.$$

The difficulty evidently arises in estimating $\bar{V}_T$. It is impossible to obtain consistent estimates for σ_1^2 , for all i , without further restrictions on these variances. But it is possible to obtain a consistent estimator of the limit of the weighted average

$$T^{-1} X' \Phi X = \frac{1}{T} \sum_{i=1}^T \hat{u}_i^2 X_i' X_i$$

With non-stochastic regressors, V_T is easily obtained by replacing the i^{th} diagonal element of Ω , σ_1^2 , with the estimated value $\hat{u}_1^2$, where $\hat{u}_1 = (y_1 - X_1 \hat{\beta})$. Having obtained the asymptotic heteroskedasticity-consistent covariance matrix estimator, hypothesis tests can be performed in the usual way.

A major advantage of specifying a probability model in a linear fashion is the uncomplicated interpretation of parameter estimates. The estima-

ted coefficient of an independent variable indicates the amount of change in the dependent variable, for a given unit change in X. That is, it indicates directly the marginal effect of X on the probability. The regression coefficient of a given independent variable shows the change in the conditional probability for a one unit change in the variable. Furthermore, in a linear model the probability is not restricted to lie along a logistic or a cumulative normal curve.

3.4. Regression Results

Regression results are summarized in Table 3.3. Consider first the results shown in equation (1). The dichotomous variable depicting the incidence of a contract employing resources which otherwise would have been idle was regressed on eight firm characteristics and an industry variable. Consistent with prior expectations the two firm specific variables capturing the degree of specialization of the firm's research establishment, namely the proportion of R&D personnel with a Ph.D., and the proportion of Capital to Current R&D expenditures averaged over three years, are positive and statistically significant at the 95 percent confidence level for a two-tailed test.

The age of the firm variable has a significant negative coefficient, reflecting a greater ability to manage idle resources within the firm. The coefficient of the variation of self-financed R&D spending is also negative and significant at the 95 percent level. This implies that companies with a relatively greater variation in self-financed R&D, tend to make less use of government R&D contracts to even out their expenditures. This result also raises the possibility of a simultaneity problem. Past variability of self-financed R&D may have been a consequence of a long-standing inability to obtain government R&D contracts.

Contrary to expectations, the proportion of R&D personnel to total employment is negatively related to the probability of a contract employing idle R&D factors. This could be either because, firms with high RRND values also have less variable demand (lower $P(I)$), or they make greater use of lay-offs or private sector contracts. Whatever the reason, this result is not compatible with the argument that the smaller the relative size of R&D staff, the more readily it can be reallocated internally.

Both the size of the firm and ownership are negatively correlated with the dependent variable. However, only the ownership variable is statistically significant. This is consistent with our expectations. Whether a firm is in the manufacturing or service sector does not appear to be an important factor in determining the likelihood of idle resources being employed. The overall R&D cycle of the industry has a negative coefficient as expected but is not statistically different from zero.

The F-statistics of equation (1) show that taken as a whole, the group of explanatory variables included in this multivariate regression equation have a statistically significant influence on the probability of contract utilizing otherwise unemployed scientists, engineers and other technicians and/or idle research facilities.

Consider next the regression results reported in columns 2, 3 and 4 of Table 3.3. The specification of the second equation (2) is different from the previous equation in that MANF is omitted. Results are generally quite similar except for CVST. The variation in self-financed R&D is no longer statistically significant when MANF is excluded.

In equation (3), the regression model allows for a non-linear relationship between the ratio of R&D personnel to total firm employment, and the incidence of a contract employing R&D factors which otherwise would

have been idle. This nonlinearity in RRND is confirmed by the statistical significance of the squared term. The coefficients of RRND and RRNDSQ are -2.9350 and +2.3959, respectively, indicating a U-shape relationship. By taking the first derivative with respect to RRND, and equating it to zero, the value of RRND which minimizes the probability that an R&D contract employs factors which otherwise would have been idle, can be determined. It can be shown that the optimal value for RRND, given that other variables are held constant, is 0.61. That is, firms which employ approximately 60 percent of total employment as research personnel, are least likely to contract with the government when there are idle R&D resources on hand. The highest RRND value in the sample is 0.96.

Equation (4) includes both RRNDSQ as well as MANF. Results generated are basically the same as those of previous equations. However, the explanatory power of RRPND diminishes and is significant at the 90% confidence for the one-tailed test. The coefficient of determination (McFadden's R^2), the Akaike Information Criterion, and the F-statistics suggest that equation (4) is superior to equations (1), (2) and (3).

3.5. Conclusion

This chapter has reported the results of an attempt to distinguish the circumstances under which government R&D contracts bid away R&D resources from other research projects. While empirical results vary from equation to equation, depending on the specification, some general tendencies emerge. The results clearly show that the incidence of a government contract crowding-out private R&D (using otherwise occupied R&D personnel and/or facilities) is greater the older and more R&D intensive the contractor, and the less specialized the contractor's R&D operation.

This implies, in turn, that the resource cost of contracting-out is lower, other things being equal, when the contractor is a newer less R&D intensive firm, with a relatively specialized R&D operation. This should not be taken to imply that procurement managers should seek these firms out. Rather it predicts that these are the firms that have a higher probability of seeking the government out, that is, of winning R&D contracts.

Of course contracting-out itself may not be the appropriate strategy, depending upon the relative costs of extramural and in-house R&D. Future surveys might usefully ask whether contract work could have been performed in-house and, if so, whether other in-house R&D would also have been crowded-out as a consequence. Ideally, crowding-out would be measured as a proportion ranging from zero to one for both intramural (government) and contract R&D. It could then be determined whether contracting-out increased or decreased the extent of crowding-out.

Another important consideration is the dynamic implication of government contracts employing idle R&D resources. To the extent that a firm can reduce the cost of having unutilized research inputs (in periods of deficient R&D demand) by employing them on government-contracts, both the scale of research activity by existing firms and the number of R&D performing firms may increase in the long run. As a consequence, the incidence and magnitude of idleness may increase. If part of the policy objective is to achieve a more complete utilization of private research personnel and facilities, the government would have to contract-out an ever increasing fraction of its R&D.

Table 3.3

Probability of a contract using idle R&D resources.
(Linear Probability Model)

Variables	Equation 1	Equation 2	Equation 3	Equation 4
Constant	1.0645** (2.77)	1.6246** (2.33)	1.6686** (2.56)	1.6480** (3.45)
RRPHD	2.6247** (3.13)	3.0220** (5.13)	1.9984** (2.62)	1.2212 (1.28)
CAP2	0.10847E-01** (2.04)	0.12276E-01** (3.30)	0.20111E-01** (3.94)	0.1956E-01** (2.51)
RRND	-0.85271** (-2.56)	-1.0536** (-3.78)	-2.9350** (-3.59)	-3.0092** (-3.46)
RRNDSQ	--	--	2.3959** (2.50)	2.8624** (2.64)
CV	-0.15906** (-2.04)	-0.90401E-01 (-1.06)	-0.94131E-01 (-1.03)	-0.1947** (-2.40)
REV	-0.93443E-04 (-1.42)	-0.80320E-04 (-1.19)	-0.97851E-04 (-1.46)	-0.12035E-03* (-1.75)
FOR	-0.32736* (-1.89)	-0.34118* (-1.99)	-0.30996* (-1.78)	-0.28377 (-1.52)
AGEC	-0.1201E-01** (-3.73)	-0.10861E-01** (-3.83)	-0.11175E-01** (-3.90)	-0.12918E-01** (-4.08)
MANF	0.20736 (1.05)	--	--	0.30162 (1.60)
IC	-0.44124 (-0.74)	-0.46124 (-0.64)	-0.36193 (-0.52)	-0.31350 (-0.63)
McFadden's				
R ²	0.48	0.46	0.53	0.59
F	3.26	3.53	3.73	3.76
AIC	24.56	24.27	23.20	22.60

* significant at 0.10 level for two-tail test

** significant at 0.05 level for two-tail test

NOTES TO TABLE 3.3

- (1) AIC is the Akaike Information Criterion which is defined as $AIC = -2 \ln L + 2k$ where $\ln L$ is the log of the likelihood function and k is the number of parameters to be estimated. The idea is to select the lowest AIC value.
- (2) McFadden's R^2 is $1 - (\ln L_1 / \ln L_0)$ where $\ln L_1$ is the log of the likelihood function of the model in question, and $\ln L_0$ is the log of the likelihood function under the null, i.e., when all slope coefficients are zero. See Amemiya, 1981, p. 1504-1506.

ENDNOTES

1. See Carmichael, J. (1981), "The Effects of Mission-Oriented Public R&D Spending on Private Industry", Journal of Finance, vol. 36, No. 3, pp. 617-627.
2. See, Lichtenberg, F.R. (1984), "The Relationship Between Federal Contract R&D and Company R&D", American Economic Review, vol. 74 (May), pp. 73-78.
3. Ibid.
4. See White H. (1982), "Instrumental Variables Regression with (ade-)pendent Observations", Econometrica, 50, pp. 483-500.
5. For a good explanation of these statistics, see Amemiya, T. (1981), "Qualitative Response Models: A Survey", Journal of Economic Literature, 18 (4), pp. 483-536.

Chapter 4

Commercial Benefits from Government R&D Contracts

4.0 Introduction

The recommendation that mission-oriented R&D be contracted-out to industry was grounded in the belief that there are many technological fall-outs or spin-offs from government R&D, and that such spin-offs are more likely to be exploited commercially by private firms than by government researchers.

The social value of economic spin-offs that arise when government research is contracted out is: the discounted sum of the additional profits earned by the contractor and other firms, as a consequence of the contract; and the additional rent which accrues to factor inputs employed by the contracting firm as a consequence of undertaking the contract.

The private value to the contracting firm of a government R&D contract spin-off is the additional profits earned (including the incremental contribution to the value or marginal productivity of self-financed research and the contribution made to specialized factors which may or may not be idle) as a consequence of the R&D project.

From an economic point of view, a contracting-out policy can be justified if there are technological spin-offs, and if the benefits from these spin-offs exceed the contracting costs. Within the framework developed in Chapter 1, contracting-out is beneficial when

$$[a_c + a_I + a_A - a_g]GB > [R(c) + C(c) - (R(g) + C(g))].$$

Secondary benefits from contract R&D, and the costs of realizing these spin-off benefits have yet to be determined quantitatively. Private and social gains from contracted R&D work have been a subject of recent

interest for researchers, industrial R&D practitioners and government policy makers. This chapter focuses specifically on the spin-off component, $(\alpha_c + \alpha_I + \alpha_A - \alpha_g)GB$. The following questions will be addressed: 1) what is the extent of spill-over benefits from government R&D contracts?; and 2) what are the determinants of a contract realizing commercial utilization?

Section 2 of this chapter provides a discussion of the recently growing literature on secondary benefits from government R&D contracts. Section 3 provides quantitative evidence of economic spillovers from the Transport Canada contracts examined. Since project officers and contractors have their own ideas about the nature and existence of spillover benefits, and these can vary considerably, their assessment of contract outcomes are separately presented and compared.

Section 4 examines and isolates statistically, factors which are likely to influence the probability of a contract generating a spin-off. This section contains the empirical model and a detailed discussion of the explanatory variables. In the last section, estimation results and some concluding remarks are presented.

4.1 Literature Review

Early debates concerning technological "fall-out" from government research and development contracts have received substantial attention. Supporters of government procurement programs have ensured that cases of spillovers in the form of civilian technological advancements are highly publicized, while critics have made the public aware of cases where government procurement has resulted in complete failures.

Economists have increasingly come to realize that there are many ways in which federal R&D can affect the economic performance of private firms, and that spin-offs from government contracts are multi-faceted. At present, some evidence as to the nature and the possible value of spin-off benefits exists. However, little evidence is available on circumstances where secondary benefits are more likely.

There have been several attempts to measure commercial benefits from R&D contracts by estimating variants of the productivity growth equation

$$p = \alpha_0 + \alpha_1 R + \alpha_2 C \quad (1)$$

where p is the rate of productivity growth, and R and C are measures of private and contracted R&D activities respectively (Griliches, 1980; Terlecky; 1980; Levy and Terlecky; 1983; and others).

These studies attempted to infer the existence of spin-off benefits from production functions estimated for individual R&D contractors or groups of contractors. Many investigators have found virtually no relationship between R&D contracts received, and subsequent growth in total factor productivity (i.e., α_0 is not significantly different from zero). This finding could be interpreted as either that there is no spin-off benefit, or that spillover benefits are inappropriable by the contractors. It, however, does not necessarily imply that there are no benefits external to the firm.

It is possible that a government R&D contract generates peripheral knowledge that is used by other firms for which the contractor receives no compensation. The extent to which this may occur would depend in part upon the type of restrictions on appropriability (such as exclusivity on commer-

cial exploitation) that government funded R&D carries. Inappropriability could also reflect the extent to which government contracts confer indirect benefits to scientists and engineers of the contracting firm who, in turn, leave the firm and perhaps join another research and development establishment, taking with them acquired knowledge and specialized skills. In such cases, the effect of federally financed R&D on productivity will not appear at the firm level. However, it is likely to be detected when the relationship is examined at the industry level.

Griliches (1980) examined the effects of self-financed R&D and total R&D expenditures on the productivity and profitability of contractors. Griliches assumed that the production function of a particular firm is presented by a Cobb-Douglas type function,

$$Q = Ae^{\lambda t} L^{\beta} K^{(1-\beta)} R^{\alpha} \quad (2)$$

where Q is the firm's output (sales, or value added), L and K are measures of labour and capital input respectively, and R is the stock of technical capital or technical knowledge. Differentiating the above expression with respect to time yields

$$q = \lambda + \beta l + (1-\beta)k + \alpha r \quad (3)$$

where q is the productivity growth, $\frac{dQ/dt}{Q}$, l , k and r are $\frac{dL/dt}{L}$, $\frac{dK/dt}{K}$, and $\frac{dR/dt}{R}$ respectively. β is the estimated factor share of labour input (average share of labour in total sales). The rate of growth of total factor productivity can be defined as

$$p = q - \beta l - (1-\beta)k = \lambda + \alpha r \quad (4)$$

α is the output elasticity of technical (research) capital, $\frac{\partial Q}{\partial R} \cdot \frac{R}{Q}$.

This enables one to rewrite expression (4) as

$$p = \lambda + \alpha r = \lambda + \rho(I_R/Q) \quad (5)$$

where ρ is the rate of return to research expenditures or the marginal product of technical capital, while I_R/Q is the net investment in research as a ratio to total output. Since measures of depreciation in research capital or technical knowledge are not available, it is generally assumed that the firm's net investments in the stock of technical knowledge, I_R , can be approximated by the firm's R&D expenditures.

Having estimated a variant of the productivity growth equation, Griliches concluded that the elasticities of contractor output with respect to total and self-financed R&D generally did not differ significantly. There is, in Griliches interpretation, an "excess return" to R&D and this return does not depend on the source of financing. That is, the productivity growth results seem to indicate spin-off benefits at the firm level. He stated that:

"In our regressions we were unable to discover any direct evidence of the superiority of company-financed R&D as against federally financed R&D in affecting the growth in productivity. It may well be the case that within any company a dollar is a dollar, irrespective of the source of financing, (p. 445)

However, when Griliches measured the respective effects of self financed and contract R&D on operating profit per dollar of assets, ($\frac{\text{value added-cost}}{\text{gross domestic assets}}$), a somewhat different story emerged. In general, the rate of return on total R&D was less than on company financed R&D (17%

and 19% respectively). Given the relatively small portion of R&D carried out under contract (Table 8.A.1, p. 448), the rate of return on the contract R&D would have to be very low (or even negative), in order to bring about the difference between the rates of return on total and company-financed R&D as reported by Griliches (Table 8.5, p. 439). Griliches' calculations are presented in Table 4.1.

Table 4.1
Gross Return on Total and Company Financed R&D
(U.S., 1966)

Industry	Annual Rate of Return	
	Total R&D	Company-Financed R&D
1. Chemicals and Petroleum	93%	103%
2. Metals and Machinery	25%	28%
3. Electrical Equipment	02%	03%
4. Motor Vehicles	23%	29%
5. Aircraft	05%	17%
6. Other	23%	26%
7. Combined Total	17%	19%

Source: Griliches (1980, p. 439), New Developments in Productivity Measurement and Analysis, ed. by Kendrick and Vaccara.

If self-financed R&D is 90 percent of the total for his sample as a whole (Griliches, 1980, p. 448, table 8.A.1), then from line 7 of Table 4.1 one can write the return on total R&D as the weighted average of the respective returns on self-financed and contract R&D.

$$0.17 = (0.90)(0.19) + (0.10)(\Delta)$$

$$\text{Therefore } \Delta = (0.17 - (0.90)(0.19))/0.1 = -0.01$$

This latter finding does not seem to be consistent with Griliches' earlier conclusion.

Terleckyj (1980) used the same model as Griliches (1980) but applies it at the industry rather than the firm level. The general form of the equations estimated can be written as follows:

$$p = \lambda + \rho (I_R/Q) = a_0 + \sum_1 a_1 x_1 + \sum_j b_j I_j \quad (5')$$

where a_0 is the constant term of the regression representing the unexplained portion of residual growth, a_1 's are the regression coefficients of the variables x_1 's, which denote non R&D factors. The b_j 's are the coefficients of the different research intensities (R&D expenditures/sales), and represent the estimates of the marginal products of the respective types of R&D.

Terleckyj finds that while the gross excess rate of return on self-financed R&D ranged from 20 to 37 percent, the gross excess return on contract R&D did not differ statistically from zero (Terleckyj, Tables 6.3, 6.5, and 6.6, pp. 367-375). This does not imply that the contractor gets nothing from contract R&D. Rather, it implies that income received on contract R&D covers the costs of the labour and capital involved and no more. In essence, Terleckyj has found that there is no spin-off benefit from contract R&D.

If one accepts Griliches' productivity growth results which appear to indicate a spin-off benefit at the firm level, the apparent absence of spin-off benefits at the industry level (Terleckyj, 1980) implies that contracting firms improve their performance at the expense of non-contractors. R&D contracts therefore may redistribute productivity growth within an industry, but do not affect the aggregate amount.

Further U.S. evidence on this issue is provided by the study of Levy and Terleckyj (1983). The appealing aspect of the Levy and Terleckyj study is that government financed R&D is subdivided into contract R&D and other government R&D, and these subcomponents are entered separately into the productivity equation. This reflects a recognition that government R&D support mechanisms can not be treated as homogeneous. In addition, the study allows for a lagged influence of federal R&D on productivity. The study focuses on estimating the coefficient of government R&D in the productivity equation using aggregated time series data for the period 1949 to 1981.

Productivity, expressed as a logarithm of the output per hour was regressed on: the logarithm of the stock of fixed capital per hour; unemployment; the logarithm of the ratio of private industry R&D capital to fixed capital, and the logarithm of the ratio of government R&D capital to fixed capital. Four separate regression equations were estimated using various concepts of government financed R&D capital - total government R&D, government contract R&D and other government R&D (government funded R&D performed in universities, government facilities, and non-profit institutions).

Total government financed R&D stock has a relatively small positive and insignificant effect on productivity. When government R&D was divided into contract R&D and all other government R&D however, the results are quite different. Levy and Terleckyj have found that there are spillover benefits from government R&D contracts but not from other government R&D. The marginal product of contract R&D performed in industry was estimated at 0.094 while the marginal product of company-financed R&D was significantly higher at 0.268.

Levy and Terleckyj's empirical results show that it is important to make a distinction between types of government R&D support. A similar result was found by Link (1985). Differentiating between basic federally financed R&D and applied federally financed R&D, Link found that the effect on private productivity was statistically significant for the former but not for the latter.

Canadian evidence on this score can be obtained from two fairly recent studies by Switzer (1984) and Longo (1984). Following Terleckyj's method, Switzer estimated the respective rates of return on total and self-financed R&D at the 2 digit industry level. The study reported an average gross excess rate of return on self-financed R&D of between 60 and 70 percent. He found that the gross excess rate of return on government financed R&D was effectively zero. Switzer contends that his results are comparable to both Griliches (1980) and Terleckyj (1980).

"In all cases, the rate of return to total R&D is lower than for company R&D alone, which is consistent with Griliches (1980) and Terleckyj (1980) and may indicate diminishing return effects to R&D expenditures where government funding is concentrated. When both government and private R&D are used in the regressions as separate independent variables ... we note, however, that the estimated rate of return to government R&D is almost the same as for private R&D, although the latter is insignificant." (p. 8)

Unlike Terleckyj's U.S. data, Switzer's government financed R&D data includes both subsidies and contracts and it is likely that the contract component is very small. In so far as contracts are concerned, Switzer's findings seem to imply that there is no commercial spin-off from government R&D, and that the return on the contracted research depends upon the government use of the results. In essence, this finding implies that there is no social benefit from contracting out government mission-oriented R&D.

To the extent that contracts are involved, Switzer's results are in disagreement with Levy and Terleckyj (1983). The latter found that government contract R&D does generate intra-industry commercial spin-offs. According to their estimates, a 10 percent increase in government contract R&D would generate directly or indirectly approximately a 0.65 percent increase in private sector productivity (Levy and Terleckyj, 1983, p. 558, table 3.3, equation (3-3)).

Longo (1984) examined the return from R&D in Canada using cross sectional data from 146 firms, for which R&D information for the period 1972 to 1979 could be obtained. He found an average net return on R&D of 58 percent. This firm level estimate, taken together with Switzer's estimates implies that there are small spillover effects within the industry, in the order of about 10 percent. No distinction was made between self-financed and government financed R&D in Longo's analysis.

To date, empirical evidence on this score has been inconclusive. While some found that government R&D spending yielded positive spillovers, others found little evidence to support this contention. The extent to which a firm undertaking a government R&D contract confers inappropriable benefits to other firms is not known. In addition, very little has been said about the environment in which government R&D contracts are likely to have the most pronounced effect on productivity.

There have also been other assessments of the secondary benefits from U.S. government funded research (Arthur D. Little, 1976; The Rand Corporation, 1976; and The Stanford Research Institute International, 1978). These studies attempted to identify factors associated with the success or failure to implement Federal research results, and to estimate the benefits

(consumer's surplus and producer's benefits from cost reduction) from the commercialization of government R&D results. Good summaries of these studies are provided by Merrill (1979) and Bean and Roessner (1979). While the studies deal with "spin-offs", they are not concerned specifically with the secondary benefits from contracted R&D. Rather, they address the role of various technology transfer programs, such as the NASA technology utilization program, and the Department of Defense Scientific and Technical Information Program, in promoting the commercial exploitation of government funded technology.

4.2 Commercial Benefits from Transport Canada R&D Contracts

4.2.1 Spin-off Benefits from Transport Canada R&D Contracts

Spillovers from technical advances in general have recently received increasing attention (Griliches, 1979; Scherer, 1981, Bresnahan, 1986; Jaffe, 1986; and others). Specifically it has been pointed out that many civilian technical advances were developed as a result of government contract R&D work (Ault and Smith, 1979; Carmichael, 1981; Nelson, 1981). Some of the technical fall-out or spin-offs cited include: the earlier vintage of computers; semi conductors; heart pacemakers; cryogenic insulation materials; automatic instrument landing systems; jet engines and air-frame designs; and artificial kidneys.¹ Measurements of the social value of such spillovers would greatly illuminate the magnitude of the beneficial contribution government R&D contracts have made, and would provide guidance for a sensible allocation of R&D performance.

This section provides some information on R&D contract spin-offs. Although it cannot pronounce upon the economic values of the spin-offs, it can present quantitative evidence on the proportion of government R&D con-

tracts that have realized various types of spillover benefits. The study focuses on the "direct commercial benefits" accrued to the contracting firm and determines the sensitivity of its existence to some economic factors. These factors include the contractor's ability to exploit commercially technologies developed under contract, the ability to innovate, and the technical opportunity of the research work. The empirical analysis can then provide a list of factors likely to increase the probability of a contract realizing commercial spin-offs.

4.2.2 Outcomes of Transport Canada R&D Contracts: Project Officer Survey

Spillover benefits are divided into two types: Direct Benefits; and Indirect Benefits. Direct commercial benefits are defined to have occurred when a contract has resulted in the development of a new or improved product, process or of technical information sold or licensed to parties other than the government.

Indirect Benefits are defined to have been realized if the contract:

- (a) contributed to the successful completion of R&D projects;
- (b) allowed the contractor to keep a research team together when it might otherwise have had to lay-off or divert staff to non-R&D activities;
- (c) allowed the contractor to learn new technical skills which were subsequently used to develop new products or processes or to engage in more advanced R&D work;
- (d) assisted the contractor to acquire or maintain research facilities which could not otherwise exist in Canada.

From the individual project officers surveyed, information about spin-off benefits from Transport Canada Contracts was obtained. The extent to which these benefits were realized is summarized in Table 4.2.

Table 4.2

Spillover Benefits (Project Officer Survey)

<u>Benefit</u>	<u>Percentage of Contracts in which Benefit Realized</u>
(1) Direct Benefit	35.0
(2) Indirect Benefit:	
(a) Successful Completion of Subsequent Projects	70.0
(b) Keep Research Team Together	50.0
(c) Acquire New Technical Skills	80.0
(d) Discerning New Opportunities	47.5
(e) Acquire or Maintain Specialized Research Facilities	22.5

Follow-on research financed by sources other than the government is considered by some as a category of indirect spin-off benefits from R&D contracts. According to the project officers surveyed, company financed R&D increased as a result of the contract in 57.5 percent of the cases.

4.2.3 Outcomes of Transport Canada R&D Contracts: Contractor Survey

Contractors were asked to respond to similar questions relating to the realization of direct and/or indirect commercial benefits. Respondents were asked to indicate whether the technology or information developed under each of the sample contracts involving them was utilized and, if so, how. Forms of utilization included: (a) direct commercial application by the contractor or by other companies; (b) utilization by the government; and (c) usage as a base for follow-on research for the contractor's own purposes or for the government.

Direct commercial application is referred to as "direct commercial benefit". Admittedly, the benefit term is used loosely, for the mere

commercial application of the technology does not imply that a net benefit in the economic benefit:cost sense has been realized. Similarly, the use of contract technology by the government is referred to as a "direct government benefit".

Spin-off benefits from government contracts include the direct benefits from commercial exploitation of technologies generated, and some other indirect benefits such as: (a) contributions to the successful completion of other projects being conducted by the contractor; (b) improvement of the contractor's other products; (c) learning a new technology for the purpose of entering a new line of business.

The respective percentages of the sample contracts generating each of these spin-off benefits are reported in Table 4.3.

Table 4.3

Spillover Benefits (Contractor Survey)

<u>Benefit</u>	<u>Percentage of Contracts in which Benefit Realized</u>
(1) Direct Commercial Benefit	35.0
(2) Indirect Benefit:	
(a) Contributed to Successful Competition of Other Projects	40.0
(b) Helped to improve the product line	50.0
(c) Assisted in learning a new technology	50.0

4.2.4 The Contractor Survey versus the Project Officer Survey

An interesting by-product of the study is a comparison of the respective assessments of the contractors and the project officers pertaining to commercial benefits resulting from each contract. Both project officers and contractors were asked essentially the same question (Appendices 1 and 2). Did they give the same answer?

The tabulation responses of both groups are presented in Table 4.4.

Table 4.4

Contractor versus Project Officer Commercial Benefits Assessment

		<u>Project Officers</u>	
		No Direct Commercial Benefits	Direct Commercial Benefits
<u>Contractors</u>	No Direct Commercial Benefits	47.5%	17.5%
	Direct Commercial Benefits	17.5%	17.5%

In terms of the proportion of contracts for which R&D results have been utilized commercially, both project officers and contractors agree that 35.5 per cent of the cases realized commercial benefits, and 65.5 did not. However, with in the group of contracts realizing commercial spin-offs, only half was considered to have commercial benefits by both respondents. In 47.5 per cent of the contracts, the respondents agree that there was no spin-off, 35.0 per cent was deemed to have realized commercial benefits by either the contractor or the project officer, and 17.5 per cent was considered to have commercial benefits by both. This indicates that "commercial benefits" from a contractor's view point may not constitute "commercial benefits" from a project officer's point of view, and vice versa. It is reasonable to postulate that contractors possess better information concerning commercial benefits than project officers, and as such, the contractor's definition is employed in the following sections.

4.3 Commercial Benefits from Transport Canada R&D Contracts: A Multivariate Regression Analysis

4.3.1 Factors Associated with the Realization of Direct Commercial Benefits: A Multivariate Analysis

Factors influencing the incidence of a contract realizing commercial spin-offs have been investigated (Harbridge House, 1968; Nelson, 1982; and Mansfield and Switzer, 1984). Previous analyses are, however, still preliminary or anecdotal. The purpose of this section is to determine systematically, the sensitivity of the existence of spin-offs to various economic factors. Explanatory variables considered include: the characteristics of the contractor; the characteristics of the research project commissioned; and the nature of the contractual agreement. The commercialization of contract technology would depend upon the appropriability provision of the contract and the ability of the firm to exploit such technology. The effect of a government contract is likely to differ from firm to firm, depending upon the nature of the firm's activities and motives. The innovative outcome can also be influenced by the nature of the government sponsored technology itself. This chapter delineates the type of environment that is most conducive to the commercial exploitation of government R&D results. Special attention is given to the assignment of exclusive rights to technologies developed under contract.

Explanatory variables to be included in the model are discussed in turn. This is followed by a discussion of the econometric techniques utilized, and the results.

4.3.2 The Explanatory Variables

(1) Property Right (RY)

One of the policy variables that has received a great deal of attention over the years, particularly in the discussion of technological

progress, is the disposition of property rights to new technologies and/or information. The economic consequences arising from changes in the allocation of property rights are well examined by Alchian (1974), Alchian and Demsetz (1972), Furubotn and Pejovich (1972), Williamson (1975, 1979) and many other analysts. In the context of technological progress, the issue has been investigated by Arrow (1962), Mansfield (1986) and Scherer (1983, 1986) amongst others. With respect to innovations developed under government sponsored R&D projects, Collins, Ferejohn, and Kevles (1974) suggest that changes in rights assignment, cause a redistribution of wealth and precipitate other effects such as: (i) shifts in demand and supply for government financed R&D and in the rate of technological innovation and dissemination of technological knowledge; (ii) shifts in the commercialization incentive; and (iii) shifts in the economic concentration in the industry. The principal consideration here is how rights assignment affects the commercialization incentives of the firm.

As a result of its concern for the incentive to commercialize, the United States government recently amended its patent policy to allow, as a general rule, small businesses and non-profit organizations to retain title to patents over innovations arising out of federal R&D projects. Prior to this, government agencies followed non-uniform practices (Pickarz, 1983). Some pursued a "title" policy where the agency claimed title to all patents, while others pursued a "licence" policy where industrial contractors were allowed to retain title to patents over technology developed under contract.

License policy advocates argue, that government ownership of principal rights reduces the normal incentive for industry to commercialize patented

inventions. Since the government itself is not in the business of marketing inventions, such commercialization would have to be contracted out to private industry. There is therefore a cost advantage in allowing the original contractor to hold the title. This view, however, is not without critics.

Title policy advocates view research output (principal and peripheral), as a product of the contract. The rights of the invention should therefore be the property of the party that has commissioned the research. They believe that "if the contractor is allowed to retain the rights, the government is essentially giving away an element of the public domain for monopolistic price exploitation of the public." (Collins, Ferejohn and Kevles, 1974).

In Canada, property rights to all research output are typically vested in the government (see Chapter 2).²

This leaves the contractor with no right to any research results, incidental or otherwise, from R&D financed by the government. The Science Council of Canada (1976) surveyed a number of R&D performing firms and cited comments to the effect that there is no incentive to explore the potentially profitable application of government research, since there is no exclusive right to products developed under government R&D contracts. Some firms fear that their competitive positions could be compromised because the government could turn over the R&D results developed under contract to a competing company.

In some cases, however, the government has explicitly relinquished claim to the principal rights over innovations conceived under contract. In the sample of R&D contracts collected, the government waived the rights to such technologies in 32.5 percent of the cases examined.

It should be noted that when a company retains rights to information or technology arising from an R&D contract, the government is granted an irrevocable royalty free license to manufacture and to use anywhere any article covered by any patents resulting from the contract.

Several questions arise concerning the relationship between the distribution of rights and the incidence of commercialization. Does the assignment of property rights matter? What is the effect on the incentives of the firm if it has the exclusive right to the commercial application of technologies conceived under contract? To what extent would the incidence of commercialization of government funded inventions decline in the absence of exclusive rights for commercial exploitation?

By way of examination, consider a firm engaging in government contract R&D. Its principal objective is to maximize profits (π) by performing self financed and government sponsored research. It is postulated that the profit function can be written as

$$\pi = \phi c(l) - (w-r)[L+l] - \lambda[\bar{g} - g(L, l)] \quad (6)$$

where ϕ = the extent to which the firm can commercially exploit outcomes from government research

$c(l)$ = excess research or spinoff commercial research production function

w = per unit wage rate

r = the reimbursable portion of the unit cost of labour where $0 < r \leq w$

L = contract specific labour

l = general or commercial oriented labour

$\bar{g}$ = minimum delivery standard specified by the contract.

$g(L, l)$ = production function of government defined research output

It is assumed that the marginal productivity of labour is positive, but falling as l increases. That is, both c_l and $g_l > 0$ and c_{ll} and $g_{ll} < 0$.

To maximize profits, the firm chooses optimal l and L subject to the minimum delivery standard constraint. Taking the derivative of the profit function with respect to the choice variables l and L , and the constraint parameter λ , the following first order conditions are derived.

In the situation where the government reimburses the firm for all costs, r is equal to w . The profit function (π) can then be written as

$$\pi = \phi c(l) - \lambda(\bar{g} - g(L, l)) \quad (7)$$

First order conditions and interpretation are as follows.

$$\frac{\partial \pi}{\partial L} = \lambda g_L = 0 \quad (8.a)$$

$$\frac{\partial \pi}{\partial l} = \phi c_l + \lambda g_l = 0 \quad (8.b)$$

$$\frac{\partial \pi}{\partial \lambda} = g(L, l) - \bar{g} = 0 \quad (8.c)$$

In the case where all costs are reimbursable, firms will allocate L and l such that respectively, the marginal contribution of an additional unit of L to the fulfillment of the R&D contract is equal to zero, and the value of commercial output generated by l together with its contribution to the government required product is also zero. This is similar to the true cost plus fixed fee contract in terms of incentives. The effect of property rights on the incentive to commercialize is determined easily from the second order conditions. It can be shown unambiguously that

$$\frac{dl}{d\phi} > 0$$

Totally differentiating the foregoing first order conditions, the effects of changes in the various exogeneous variables on the optimal commercially oriented labour and government contract specific labour can be traced. Using Cramer's rule, the effect of changes in property rights on the allocation of optimal l holding other exogeneous variables constant can be determined. It can be shown that

$$\frac{dl}{d\phi} = \frac{\det \begin{bmatrix} \lambda g_{LL} & 0 & g_L \\ \lambda g_{lL} & -c_l & g_l \\ g_L & 0 & 0 \end{bmatrix}}{\det \begin{bmatrix} \lambda g_{LL} & \lambda g_{Ll} & g_L \\ \lambda g_{lL} & \phi c_{ll} & g_l \\ g_L & g_l & 0 \end{bmatrix}} = \frac{\begin{vmatrix} \lambda g_{LL} & 0 & g_L \\ \lambda g_{lL} & -c_l & g_l \\ g_L & 0 & 0 \end{vmatrix}}{|D|} \quad (9)$$

For a maximization problem, the determinant of the bordered Hessian is positive, given that the objective function is quasi-concave and the constraint set is convex. Solving the above equation,

$$\frac{dl}{d\phi} = \frac{g_L^2 c_l}{|D|}, \text{ implies that } \frac{dl}{d\phi} > 0 \quad (10)$$

That is, provided that $c(l)$ and $g(L, l)$ are concave, the property right has as before, an unambiguously positive effect on the effort devoted to commercialization and therefore on the equilibrium amount of commercialization.

Of course, this indicates only the partial effect of a change in the parameter ϕ on l and thereby, the probability of a commercial spin-off. The objective of this comparative static exercise and similar exercises in other sections is to calculate the response of the contractor under various contractual licenses, and make empirical statements about their relationships.

A salient feature of R&D contracting-out is that when one or more parameters are altered, other terms of the contract do not necessarily remain the same. For instance, a higher ϕ value should increase profits on each project and in turn invite competition along some of the other contractual dimensions. With higher ϕ values, there are additional benefits that the government should expect the contractor to receive from commercialization. In turn, it could expect other returns from the contractor, perhaps in terms of a lower government share of R&D costs (r) or more government specific R&D benefits (g) for a given contract price. ϕ and other contractual parameters are subject to negotiation and are determined endogeneously. The government should try to structure a contract, taking into account the benefits to the contractor from a higher ϕ value, in such a way as to maximize its own preference function.

From the regression analysis, this study will be able to determine the effect of changes in ϕ on the probability of commercialization. The government might be interested, however, in how changes in the ϕ value and/or other parameters, affect the profitability of the contractor. With such information the government could extract additional benefits from the contractor and economize on public R&D revenue by trading off, for instance, a higher value of ϕ for a smaller share of the R&D cost. This important issue, however, must be examined quantitatively with a different data set.

(2) Cost Sharing (CS)

In general, government R&D procurement follows a simple cost-reimbursement contract with a negotiated maximum price. Under cost reimbursable arrangement, the government is liable and will reimburse all allowable audited costs incurred by the contractor and, in addition, will

pay the contractor a fixed fee (profit) normally calculated as a percentage of the total contract price.

In addition to the cost-reimbursement structure with a ceiling price provision, R&D performance contracts may take the form of "cost-sharing" agreements, where allowable R&D costs are shared based upon a negotiated proportion. From the interviews conducted, it appears that, in the view of R&D contracting officers, provisions for sharing R&D costs, ensure technical success and perhaps even increase the likelihood of commercialization. The financial stake of the contracting firm in the project itself is viewed as a tangible expression of intent to use. A contractor's financial contribution is believed to increase his incentive to realize commercial benefits. However, as the model will illustrate below, having the contractor share the cost of R&D would generate precisely the opposite effect. Consider the profit function discussed earlier (equation 6).

Differentiating the profit function with respect to the choice variables and λ , three first order conditions are obtained.

$$\frac{\partial \pi}{\partial L} = r - w + \lambda g_L = 0 \quad (11.a)$$

$$\frac{\partial \pi}{\partial l} = \phi c_l + r - w + \lambda g_l = 0 \quad (11.b)$$

$$\frac{\partial \pi}{\partial \lambda} = g(L, l) - \bar{g} = 0 \quad (11.c)$$

The firm will allocate contract-specific labour up to a point where its contribution is equal to the wage rate less the amount reimbursable by the government. The allocation of general commercially oriented labour l , will be such that the sum of marginal commercial value of an additional

unit of this labour and its contribution towards the fulfillment of the terms of the contract is equal to the wage rate less the reimbursable portion.

In addition, in equilibrium, the marginal contribution of contract-specific labour is greater than the marginal contribution of commercially oriented labour to the fulfillment of contractual requirements. Since

$$\frac{\lambda g_L}{\lambda g_i} = \frac{w-r}{w-r-\phi c_i}$$

given that $\phi c_i > 0$, $g_L > g_i$ at the optimum.

The effect of a change in the cost sharing parameter on the effort devoted to commercial ventures can be determined. An increase in the firm's share of R&D costs is represented by a reduction in r . Let $k = 1-r$ where k is the firm's share in the R&D costs, and $dk = -dr$. It can be shown that

$$-\frac{d\ell}{dk} = \frac{d\ell}{dr} = \frac{g_L^2 - g_L g_i}{D} = \frac{g_L (g_L - g_i)}{D} \quad (12)$$

where as before, the determinant of the bordered Hessian has a positive sign. Therefore

$$\frac{d\ell}{dr} \geq 0 \quad \text{if } g_L \geq g_i \quad (13)$$

From the first order conditions, it can be determined that at the respective profit maximizing conditions for L and i are

$$\lambda g_L = w-r \quad \text{and} \quad \lambda g_i = w-r-\phi c_i$$

and therefore

$$\frac{\lambda g_L}{\lambda g_i} = \frac{(w-r)}{(w-r-\phi c_i)} \quad (14)$$

Presuming ϕc_1 is positive, the above condition implies, that g_L must be greater than g_1 at the optimum. Thus $\frac{dl}{dr} > 0$, and since the firm's share of costs (k) is one minus r , then it follows that $\frac{dl}{dk} < 0$. An increase in the firm's share of the cost has an unambiguously negative effect on the effort devoted to commercialization. The model shows that cost sharing affects commercialization in the opposite direction to that which is predicted by the practitioners.

What would happen if the government's R&D payment was constrained to some fixed ceiling price, say $\bar{R}$? The profit function would then be a kinked profit function, where before the kink,

$$\pi = \phi c(l) - (w-r)(L+l) - \lambda[\bar{g} - g(L,l)] \quad (15.a)$$

for $r(L+l) \leq \bar{R}$ and,

after the kink

$$\pi = \phi c(l) - w(L+l) - \lambda[\bar{g} - g(L,l)] \quad (15.b)$$

for $r(L+l) > \bar{R}$

That is, after the maximum contract ceiling has been reached, the cost of an additional unit of labour is borne totally by the firm.

For both before and after the ceiling price constraint, the effect of property right on the effort devoted to commercialization is unambiguously positive. The equilibrium values of L and l are different under each respective circumstance. For the profit function where $r(L+l) > \bar{R}$, the first order conditions are as presented below.

$$\frac{\partial \pi}{\partial L} = -w + \lambda g_L = 0 \quad (16.a)$$

$$\frac{\partial \pi}{\partial l} = \phi c_1 - w + \lambda g_l = 0 \quad (16.b)$$

$$\frac{\partial \pi}{\partial \lambda} = g(L,l) - \bar{g} = 0 \quad (16.c)$$

These first order conditions show that a profit maximizing firm equates the marginal contribution of government contract-specific labour to the wage rate. With regards to the firm's incentive to commercialize, the model shows that the firm will allocate its efforts to commercialize such that the sum of the marginal commercial value of an additional unit of commercially oriented labour, and its contribution towards the fulfillment of the government contract, is equal to the wage rate.

It is interesting to note that if the government can set the reimbursement constraint correctly, then the constraint $\bar{R}$ becomes redundant. That is, if they know what they are paying for, they will set the maximum limit $\bar{R}$ such that they pay the contractor just enough to ensure the minimum deliverable standard required under the contract. If $\bar{R}$ is lower than the necessary amount, the contractor will not be able to deliver unless he delivers at a loss. The interesting case then becomes one in which the government $\bar{R}$ is set higher than the limit. That is, the contractor is reimbursed by the amount more than the necessary amount to fulfill contractual requirements.

In the case where the price ceiling constraint is binding, the profit function is written as

$$\pi = \phi c(l) - w(L+l) - \lambda(\bar{g} - g(L, l))$$

and consequently,

$$\frac{dl}{dr} = - \frac{dl}{dk} = 0 \quad (17)$$

That is, changing the proportion of R&D costs which is reimbursable by the government has no effect on the amount of effort devoted to commercialization. However, the place where different regime comes in is affected by changes in r , given the size of $\bar{R}$. It should be emphasized again that this indicates only the partial effect. The comparative static exercise above holds the maximum ceiling price, $\bar{R}$, constant. This variable should be

treated as endogenous as are other contract terms. That is, contract price is not necessarily independent of the cost sharing variable, and other contractual features.

To summarize, the theoretical model shows that the partial effect of cost sharing on the amount of general commercially oriented labour is negative or neutral. Therefore, contrary to the views articulated by various project officers, the incidence of commercialization is expected to be negatively related to the cost-sharing variable.

(3) Direct Government Benefits (DG)

Direct Government benefits are defined to have occurred when a contract has resulted in the development of a new or improved product or process, or technical information, which is used by the government or its agencies. Government benefits are not realized if either the contract failed to attain its research objectives, or the results of completed contracts were not used.

It is often argued that government R&D contracts are generally oriented towards the fulfillment of some "mission-oriented" tasks related directly to departmental mandates, and have relatively small civilian components. Technologies developed under contract are often not suitable for civilian needs and consequently, little commercial spillovers have taken place (Leonard, 1971; Scherer, 1984). This point is also noted by Nelson (1982) when he stated that:

"If the public-sector needs and private-sector needs differed sharply, the procurement and applied research and development funding aspects of such policies would not facilitate the evolution of technology for the private sector." (p. 460)

and

"In the early days of these technologies, R&D aimed for a governmental purpose almost always had some commercial spillover. As these technologies matured, the governmental (military) market and the civilian market began to separate. Government financed applied research and development associated with public procurement and R&D financed by the companies themselves and aimed for products in the civilian market, become dissimilar... This fall-off in "spillover" has led to proposals that the government consciously fund projects that have likely civilian benefits". (p. 460)

Technologies which the government finds useful may be less likely than others to have commercial potential. Consequently, there may be some pressure on the government to support more civilian (market) oriented research and development work.

However, Nelson also cautioned against direct government support of market oriented technologies, and cited two major failures associated with government R&D contracts with "commercial ends": the Operation Breakthrough (house construction R&D funded by the U.S. Department of Housing and Urban Development); and the Supersonic Transport Program. Nelson attributes such government failures to the lack of information or incentive associated generally with being a major user or producer of the technology involved, and thereby the lack of commercial judgement and screening ability necessary to choose the appropriate research direction.

"The lesson here is a general one, not particular to these two cases. There are many other studied cases, most of these European, in which government has tried to identify and support products that it was hoped would ultimately prove to be commercial successes. While there are few successes, the batting average has been very low, except when the government in question has been willing to subsidize or require the procurement of the completed product as well as R&D on it." (p. 469).

Other papers such as those of Eads, Enke, Pavitt and Zysman have also found a poor payoff from large scale research and development funded by the government with intended commercial application (Piekarz, 1983).

On the other hand, it has also been argued that projects which produce information or technology which is directly usable by the government would also result in some direct commercial benefits.

Nelson (1982) cited computer and semiconductor industries as cases in which government R&D support is associated with the procurement of well defined needs for public purposes, and as cases where commercial spillovers were realized. In his view, these programs' commercial success was due to the fact that their programs' overriding goal was the fulfillment of a well-defined public sector need, and that they were administered strictly with the achievement of that goal in mind. According to Nelson, civilian benefits or commercial spinoffs are therefore more likely when the government's public purposes are well defined, and are fulfilled. The implication is that when government benefit is realized, the incidence of a contract realizing commercial application should be higher.

From the above model (equation 6), it can be shown that an increase in the government's R&D requirement may increase or decrease the amount of effort devoted to commercialization.

$$\frac{d\bar{g}}{dg} = \frac{\lambda g_{1L} g_L - \lambda g_{LL} g_1}{|D|} \quad (18)$$

If $g_{1L} > 0$, then $\frac{d\bar{g}}{dg} > 0$

If $g_{1L} < 0$, then $\frac{d\bar{g}}{dg} < 0$ iff $|g_{1L} g_L| > |g_{LL} g_1|$

The cross partial, $g_{1L} > 0$ when an increase in contract specific labour increases the innovative capability of commercially oriented labour in the fulfillment of a government contract, and vice-versa. This is likely to be

the case when government and commercially oriented labour are complementary. That is, when the firm's general lines of business R&D exhibit some technological overlaps with mission-oriented R&D, such that knowledge or expertise developed in one can be used to supplement the inventive potential of the others, in the completion of the contracted R&D.

It is assumed that the likelihood of a contract realizing government benefits (technologies emanating from federal R&D contracts that are utilized directly by the leading department or other government departments) is greater, the greater the technological requirements specified by the contract ($\bar{g}$). Thus, if government and commercial research are complements, then there would be a positive relationship between the incidence of a spin-off and the incidence of a government benefit. A dummy variable taking a value 1 for the event in which direct government benefit is realized and zero otherwise, is therefore included as an exogenous variable.

(4) Unsolicited Proposals (RW)

Mansfield and Switzer (1984) argued that whether or not a government financed R&D project results in a spinoff is likely to depend on the extent to which the contractor is involved in the formulation of the project's goals and strategies. They suggested that spinoffs are more likely in firms that have the opportunity to contribute to the formulation of the project because they would tend to suggest research strategies and goals with greater commercial possibility.

Supplementing the foregoing argument is the consideration that firms actively involved in the formulation of a research project would generally be already involved in R&D work in the same area and therefore would

already have some commercial specialization and experience. Their interest in the development of contracted technology would be in its applicability to areas relevant to their business. In other words, firms that participate and provide inputs for government R&D project development, are firms that are most capable of commercially exploiting the technologies that may arise out of those contracts.

In order to maximize spillover benefits from performing R&D work for the government, firms will select areas of government research that complement closely their own commercial interest. Moreover, when a firm is undertaking a research project within the area of its greatest expertise, spillovers with promising future benefits may be more easily recognized and exploited. For these reasons, it is expected that the coefficient of the unsolicited proposal variable will have a positive sign.

(5) Field of Technology (RM2 and RM3)

The commercialization of research results developed under contract may be influenced by the type of research being conducted. In general, it would seem that immediate commercial application of government funded technologies is less likely, when the contracted research is basic or generic research (i.e. fundamental investigation to acquire knowledge for its own sake, and when the research is in pursuit of a regulatory mandate). The type of contract more likely to generate immediate spinoffs, is a contract for applied (development) research with a relatively large component of proprietary technologies.

Nelson's (1982) case studies find "dramatic differences among the industries in the extent and kind of federal R&D support" (p. 458). While

government support of basic and generic R&D in the three defense-related industries (aviation, computer and semiconductor) has contributed many significant civilian technologies. government support of applied and development R&D has also been particularly successful in agriculture and pharmaceuticals. Government support of clientele-oriented applied research was successful in agriculture but performed poorly in the building industry. One type of R&D work that warrants no support, according to Nelson, is the government guided applied R&D with commercial ends. He believes that those types of R&D programs should be left to the private sector.

In the context of the present study, Transport Canada supports three basic areas of research and development in transportation technology: Railway and Surface technology, Air technology, and Marine (including Arctic Marine) technology. To indicate the effect of structural differences between operating requirements of each mode and differences in the technologies involved, dummy variables are included as explanatory variables. These variables may also indicate the differences in stages of the innovation cycle associated with the various modes of transportation technology.

In the Rail and Surface mode, current technology is relatively mature, and applications of the technology are more readily apparent. For these contracts, a need for new technology has often been expressed by the ultimate users (such as Canadian Pacific, Canadian National and B.C. Rail). They are projects aimed primarily at solving well defined problems. Marine research, on the other hand is a more basic R&D area (Arctic Marine technologies) in which potential commercial users, apart from the Government agency itself, have yet to be identified. The research is still at the

infant/basic stage and deals with largely unproven technologies. In addition, according to a government project officer, there are apparently few Canadian firms that can commercially exploit technologies arising out of Arctic Marine R&D contracts. This is not to say that human capital necessary for successful commercial exploitation of marine R&D will not be acquired, but it is a statement about the stage of the technologies involved and their immediate commercial potential. Capabilities can be acquired if the necessary incentives exist. Finally, Air Technology deals with the development of various advanced energy saving technologies and is generally associated with long term research projects, where the chances for immediate commercial spillovers are small. The technologies involved in the Air mode are specific to their particular uses and are, however, generally well defined.

It is hypothesized that the likelihood of a short run spinoff is higher where the technology in question is well defined and the ultimate users are identified at the outset - that is, the likelihood of a commercial spillover is expected to be greater for Rail and Surface, and perhaps Air technologies.

(6) R&D Personnel/Facility Utilization (IDLE)

Performing R&D work for the government involves scientific personnel. In its evaluation of the profitability of a project, a contracting firm must consider the alternative uses of required scientific resources at the time of the contract. A government contract may yield benefits to the firm in a variety of ways. Apart from generating incidental technologies which may be appropriated by the contractor, it could also employ scientists,

engineers and other research facilities that may otherwise have been idle. When there are idle resources, a contractor may accept a project even if it has little commercial value. The contract may allow the firm to avoid certain costs, such as the cost of laying off scientific personnel and subsequent rehiring/retraining costs and the costs of idle equipment and facilities. On the other hand, when such resources can be employed elsewhere, either on different R&D projects or other productive activities, contract research must have a greater value, or at least as great a value as that of the private activities that are crowded out. The expected flow of benefits must exceed the opportunity cost of the required inputs. Therefore, a greater probability of commercial spinoff is expected to be associated with an R&D contract that utilizes otherwise fully employed resources. Alternatively, the likelihood of a contract yielding commercial spinoffs is expected to be smaller, when it employs resources which would otherwise have been idle.

To identify the state of the firm at the time of the contract, a dichotomous regressor is employed. This variable (IDLE) is assigned a value 1, in the event that the R&D contract utilizes personnel and/or facilities that otherwise would have been idle, and zero otherwise.

(7) Nature of the Firm (MANF)

Many authors (Mansfield et al., 1982; Arthur D. Little, 1979; Nelson, 1982; and others) have attached considerable importance to the link between developers and potential users of technology for successful commercial exploitation. While the incentive for commercialization in service firms

may be as large as that of manufacturing firms, the probability of commercialization is still expected to be smaller, as service firms are less likely to be the ultimate users of new technologies, and therefore incur additional costs such as licensing costs, in arranging for commercial exploitation. The net commercial value of a new technology is reduced by the amount of licensing and related costs. The probability of a contract generating a commercial spin-off, therefore, is expected to be greater for firms with manufacturing capabilities.'

(8) Size of the Firm (REV)

A factor which has received a great deal of attention in the R&D literature is the size of the firm (Nelson, 1969; Kamien and Schwartz, 1975; and others). It has been argued that large firms can reap greater benefits from new technologies, because they can better realize economies of scale than smaller firms. Larger and more diversified firms can also produce and market a higher proportion of their R&D results (peripheral or intended) than those firms whose product line is narrow. For these reasons, size is expected to have a positive influence on the profitability of an R&D venture, and thereby, on the incentive to innovate and commercialize.

Opponents of large firm size, however, argue that R&D is more efficiently performed in smaller to medium size firms than larger ones. Inefficiencies in large corporations have often been attributed to bureaucratic inertia and complicated communication networks. In many cases, small firms have the inherent advantage of superior internal communications and provide a congenial environment for innovative processes. In Williamson's term, the problem of information impactedness is perhaps less severe in smaller

firms (Mansfield et al. 1982, p. 6-7). Empirical studies on this issue have been reviewed by Kamien and Schwartz (1975). They stated that

"Empirical studies over the last ten years have consistently shown that, while there may sometimes be certain advantages of size in exploiting the fruits of R&D, the actual R&D itself is more efficiently done in small or medium size firms than in large firms.

As a proxy for size, the contractor's total sales in the contracting year are used. The net effect of firm size on the probability of a commercial spin-off is unclear.

(9) Foreign Ownership (FOR)

Another firm specific factor likely to have an impact on the incidence of a spin-off is whether the firm performing R&D under contract is foreign controlled. It is reasonable to hypothesize that firms which are more active in a variety of products and geographic markets are more likely to be able to apply a greater proportion of their R&D output, principal or peripheral. Foreign owned firms are generally more diversified than domestically owned firms and thus possess greater opportunities to exploit contract research commercially. The incidence of a spinoff would therefore be expected to be positively associated with foreign ownership.

At the same time, it is recognized that foreign subsidiaries tend to perform a predominant amount of commercial research at the corporate headquarter, since economies of scale can be realized up to a point by centralizing R&D activities. Local contract R&D is generally performed locally and perhaps in isolation from the main line commercial research of the enterprise. Mansfield and Switzer (1985) argue that where a firm's company

financed projects are completely separated physically from its government financed projects, there is little interaction, information exchange and proper coupling of government financed and company financed R&D necessary to bring about fruitful commercial exploitation of developed technologies. This is not to say that the development of technologies does not occur, but that their commercial potential may not be easily recognized and applied. Therefore in comparison to domestic firms with proper coupling between government financed and self-financed R&D, the incidence of commercial spinoffs is likely to be lower for foreign owned firms. The net influence of this variable on the probability of a spinoff would depend therefore, on the relative effect of these opposing tendencies.

(10) Proportion of R&D Financed by Government (RCONT)

It is difficult to anticipate how the incidence of a spin-off may be affected by how much R&D a firm undertakes for the government. It is possible that firms heavily involved in government R&D work may attach little importance to the commercial potential of by-product technologies. There may be a lack of interest in commercially exploiting technologies developed under contract, because these firms tend to see the government rather than the civilian market, as the ultimate consumer of their R&D results. Their income is directly tied to the completion of government mission-oriented tasks and not to the application of the technology itself (or through licensing it to other users). Therefore, firms which traditionally receive heavy government R&D support in the form of R&D contracts are expected to exhibit a lower incidence of commercial spinoffs.

On the other hand, it is possible that enterprises heavily involved in government R&D work may specialize in projects that are likely to have commercial spinoffs. If they realize significant spinoffs, they are also more likely to have a special marketing division set up to commercially apply the R&D results. Therefore, the incidence of commercial spinoffs may be positively related to the proportion of R&D contracts received by the firm. It should be pointed out that much of the R&D performed under contract could have been initiated by the contractor, and therefore, some the influence will be partially picked up by the unsolicited proposal variable. For these reasons, it is difficult, therefore, to predict how this variable may influence the probability of a spinoff.

The Harbridge House (1968) study found that the mixture of government and commercial work done within a firm proved to be a significant factor in determining the utilization of government funded R&D. The study found that the most promising mix for commercial spin-offs seems to be between 20% and 80% government business (p. iv). The implication is that the underlying relationship may be non-linear, and as such, the square of the proportion of R&D financed by the government (RTSQ) is included in the model.

(11) Age of the R&D Contractor (AGEC)

The ability to seek out and assess technologies, peripheral or otherwise that yield commercial payoffs, should increase with the research and marketing experience of the contractor. Results of research and development are often unpredictable. The precise outcome of a scientific search for a new product or process is never clear, and success, or failure, of an

R&D activity is revealed only after the fact. Often the discovery of peripheral technology will prove to be more valuable to the firm than the initial intended technology. The uncertainty associated with research activity should decline as research and research management experience accumulates.

In addition to technological uncertainty, there is also market uncertainty. It is very difficult to predict with any degree of confidence which technologies will be profitable. Successful commercial application of a technology does not depend on the form of technology alone, but depends also on the way it is marketed and commercialized. Therefore, product market experience - the ability to plan and manage financing and cash flow, and to hire and retain personnel are likely to be critical factors.

Evidence of experience would be provided by the age of the firm, defined as the number of years elapsing from incorporation to the year of the contract (see Mansfield, 1982, p. 74). Since the age-experience relationship may be nonlinear, both age and age squared (AGESQ) will be tested in the regression analysis.

(12) Average Number of Patents Granted (FP)

Number of patents is sometimes used as a crude index of the innovative capability of a firm for a particular period of time. There are many disadvantages of using patent statistics in this way. For instance, patent statistics provide no information as to the value of the innovations being introduced or commercialized, and their importance to society. Furthermore, the proportion of the total innovations that are not patented (trade secrets) may be substantial. Nonetheless, if it is assumed that there are

no significant differences in the proportion of total innovations that are patented across firms, then the average number of patents granted may be employed as a proxy for the innovativeness and scientific/technical capability of the firm's research establishment.

To generate a careful measure of inventive capability of the contracting firm and not of other affiliated firms, it is important that the number of patents granted refers only to the number of patents granted to Canadian inventors. To construct this variable, patent information provided by the Department of Consumer and Corporate Affairs as available in the Canadian Patent Office Records is employed. The number of patents granted to the Canadian inventors from each of the contracting firms was counted and recorded for the time period 1977 to 1984. The average number over this period was then calculated by dividing the aggregate patents received by the number of years. For firms that were incorporated after 1977, the aggregate patents received was divided by the age of the firm. To the extent that these patent statistics measure firms' inventiveness, it is expected that the variable is positively related to the incidence of commercial benefits.

(13) R&D Contract Size (CONTC)

The innovative process is generally a sequence of discrete research steps involving various forms of uncertainties. It can be argued that uncertainty as to objective and procedure inherent in all development projects can be minimized by recurring appraisals at various levels. By employing a series of small specific contracts rather than one general large contract for R&D procurement, objectives and the precise steps to be

undertaken can be identified in successively more specific stages, each involving interaction between the agency and the contractors involved. Successive contracting permits frequent evaluation and minimizes the need for the government to intervene in the internal management of the contractor. Regular evaluation of each research milestone requires that the contractor exercise greater control over technical personnel, and encourages more diligent performance. A series of contractual relationships allows the government to minimize its monitoring costs, and provides incentives for contractors to efficiently carry out governmental R&D tasks. The underlying assumption here is that the government and commercial benefits are substitutes. Given this rationale, there is possibly less opportunity in smaller R&D contracts for the discovery of peripheral technologies which may be commercially useful. However, if the realization of government benefit is a precondition for the realization of commercial benefits, smaller contracts may indeed be positively associated with the incidence of spinoffs. Because of these tendencies, it is difficult to predict the sign of the contract size a priori.

(14) Time Lag Since Project Completion (CLAG)

Since there may be considerable development work following the completion of a government contract before R&D results can be commercialized, it is natural to expect that older contracts with a longer time span between completion and the time of analysis, would have had a greater chance for commercialization. Recently completed contracts may have generated useful technologies, however, they may not as yet have developed far enough for market introduction, and as such, may not have been commercially utilized.

For this reason, a positive coefficient is expected for the variable denoting time lag since project completion. This variable may also capture some latent characteristics of the R&D work of a different vintage. The affect of this latter consideration on the probability of a spin off is unclear.

4.3.3 Model Specification

The empirical model to be estimated can be summarized by the following general functional-form equation, where the i subscript denotes each individual contract, and the j subscript denotes each individual contracting firm.

$$P_{ij} = f(RY_{ij}, CS_{ij}, DG_{ij}, RW_{ij}, RM2_{ij}, RM3_{ij}, IDLE_{ij}, MANF_j, REV_{ij}, FOR_{ij}, RCONT_{ij}, AGE_{ij}, FP_j, CONTC_{ij}, CLAG_{ij})$$

where

- P_{ij} = probability that the i^{th} contract to the j^{th} firm realizes commercial benefits.
- CS_{ij} = 1 if cost-sharing arrangement is employed
0 otherwise
- RY_{ij} = 1 if contractor retains property right.
0 otherwise
- DG_{ij} = 1 if contract realizes government benefit
0 otherwise
- RW_{ij} = 1 if unsolicited contract
0 if otherwise
- $RM2_{ij}$ = 1 if technology is Surface and Rail
0 if otherwise
- $RM3_{ij}$ = 1 if technology is in Air
0 otherwise

$IDLE_{ij}$ = 1 if contract employs resources which otherwise would have been idle

0 otherwise

$MANF_j$ = 1 if contracting firm is a manufacturing firm

0 otherwise

REV_{ij} = firm size (revenue of the firm in the year of the contract)

FOR_j = 1 if foreign owned

0 otherwise

$RCONT_{ij}$ = proportion of total R&D performed financed by the government in the contracting year

$AGEC_{ij}$ = age of the firm (years since incorporation) at the time of the contract

FP_j = average number of patents of the firm (stock of patents)

$CONTC_{ij}$ = size of the contract

$CLAG_{ij}$ = number of years since the completion of the R&D contract to the years of analysis, 1984

4.3.4 Estimation Method

It is assumed that the true probability of a contract realizing commercial utilization or commercial spinoff is a linear function or a logistic function of the independent variables. Regression results are then estimated by Ordinary Least squares with heteroskedasticity correction and Logistic maximum likelihood method. The observed binary variables are equal to the true probability of a spinoff plus a random error, in the linear case. In the logistic model, the observed binary variables incorporate the true probability of a spinoff and the error terms in a non-linear fashion.

In Logit, the probability of a spinoff can be specified using the function

$$p = 1/[1 + e^{-X\hat{\beta}_j}]$$

where X is a matrix of independent variables, and β is a vector of unknown coefficients.

In the linear probability model, the estimated coefficient of an independent variable, indicates the amount of change in the dependent variable for a given unit change in X . That is, it indicates directly the marginal effect of X on the probability. It is possible with the Linear Probability Model that the predicted value lies outside the $[0, 1]$ probability bound.

With the logistic function, the predicted value of P_1 must fall between zero and one. By solving for the logarithm of the odds of realizing commercial spinoffs, the logistic function is transformed into a linear equation.

$$\ln \left(\frac{P_1}{1-P_1} \right) = X\hat{\beta}$$

The logit coefficient for X_j , $(\hat{\beta}_j)$ shows the percentage change in the log of the odds for a one unit change in X_j . The marginal effect of X_j on P_1 is given by

$$\frac{\partial P}{\partial X_j} = \hat{\beta}_j \frac{e^{-X\hat{\beta}}}{(1+e^{-X\hat{\beta}})} = \hat{\beta}_j P (1-P)$$

From above, the elasticity of P with respect to variable j can be written as

$$\eta_j = (\bar{X}_j / P) (dP/dX_j) = \hat{\beta}_j (1-P) \bar{X}_j$$

It is customary to evaluate dP/dX_j and η_j at the sample means of the X_j and at $\bar{P}$, where $\bar{P}$ is the proportion of contracts in the sample that have realized commercial benefits.

In the case where the independent variable X_j is a dummy variable, the interpretation of the estimated coefficient is slightly different from the

Table 4.5
Probability of a Contract Realizing Commercial Spin-offs
(Linear Probability Model)

INDEPENDENT VARIABLES	COEFFICIENTS AND T-STATISTICS			
	1	2	3	4
CONSTANT	0.36271 (1.20)	0.36327 (1.15)	0.51514 (1.84)	0.53133 (1.83)
RY	0.68565 (2.96)	0.68510 (3.04)	0.70193 (3.05)	0.68310 (3.09)
RW	0.25940 (1.97)	0.25937 (1.97)	0.25913 (2.18)	0.25786 (2.17)
MANF	-0.11235 (-0.42)	-0.11250 (-0.42)	0.10352 (0.37)	0.094722 (0.34)
AGEC	-0.017 (-2.56)	-0.01688 (-3.97)	-0.0162 (-2.65)	-0.01839 (-4.34)
AGESQ	-0.74E-06 (-0.012)	--	-0.254E-04 (-0.43)	--
FOR	-0.41547 (-2.04)	-0.41450 (-2.19)	-0.51004 (-2.57)	-0.47548 (-2.62)
REV	0.23 (3.59)	0.23E-06 (3.58)	0.235E-06 (4.02)	0.226E-06 (3.80)
RM2	0.37328 (1.78)	0.37355 (1.78)	0.37135 (1.75)	0.38054 (1.79)
RM3	-0.3932 (-1.53)	-0.39234 (-1.63)	-0.47459 (-1.61)	-0.44398 (-1.80)
IDLE	-0.46860 (-3.10)	-0.46832 (-3.17)	-0.54445 (-3.47)	-0.53375 (-3.47)
RCONT	-0.14937 (-0.47)	-0.15027 (-0.48)	-1.3544 (-2.50)	-1.3642 (-2.50)
RTSQ	--	--	1.4021 (2.04)	1.3781 (2.06)
FP	0.74E-02 (2.96)	0.741E-02 (2.95)	0.709E-02 (2.95)	0.698E-02 (2.88)
DG	0.14489 (0.56)	0.14514 (0.56)	0.03131 (0.11)	0.04159 (0.15)
CONTC	0.91E-06 (1.40)	0.91E-06 (1.41)	0.807E-06 (1.23)	0.817E-06 (1.25)
CLAG	0.05523 (1.66)	0.05524 (1.67)	0.036230 (1.07)	0.036741 (1.10)
MCFADDEN R ²	0.68	0.68	0.75	0.75
AIC	24.6804	23.6805	13.88463	12.91777
F-Statistic (d.f.)	2.43 (15,24)	2.71 (14,25)	2.52 (16,23)	2.80 (15,24)

above. A dummy explanatory variable subdivides the population into 2 groups and the coefficient measures the difference between the groups (Ben-Akiva and Lerman, 1985). Therefore, with a binary independent variable, it would be inappropriate to examine the marginal effect and discuss the measure of elasticity in a meaningful way.

The t-statistics from the logit estimation can be used in a test of significance directly. Table 4.5 contains the ordinary least squares regression of the dichotomous commercial spinoff equation, and Table 4.8 contains the dichotomous logit spinoff equation. The value of η_j and $\frac{dP}{dx_j}$ are also reported where appropriate in Table 4.8.

Three different measures of goodness of fit are provided. To measure how well the model fits the data, McFadden's R^2 statistic is often used. The statistic is defined as $1 - l(\beta) / l(\beta_0)$, where $l(\beta)$ is the value of the log likelihood function at the estimated parameters and $l(\beta_0)$ is the log likelihood function when the parameters are equal to zero. The higher the statistic, the better the model fits the data. The second measure is the Akaike Information Criterion (AIC). This statistic is defined as $-2l(\beta) + k$, where $l(\beta)$ is as defined above, and k is the number of explanatory variables in the model. In order to choose the model that performs the best, one selects the model with the lowest AIC value. In addition to McFadden's R^2 and the Akaike Information Criterion statistics, Table 4.10 also indicates the proportion of correct predictions. This value shows the proportion of the observed occurrences that can be predicted correctly by the model (Amemiya, 1981).

4.3.5 An Empirical Problem

Unfortunately, the data are such that both property rights vested with the contractor and cost sharing almost always occur together. This imposes a significant identification problem. With their joint occurrence, it is not possible to specify the model with both variables included as separate explanatory regressors. Empirically, the implication is that their independent effect on the incidence of commercial spinoffs can not be determined. However, the theoretical model suggests that cost sharing should have a negative or no effect while the property right variable should have a positive effect on the incentive to commercialize.

If a negative effect is observed, this would imply that it is the cost sharing that is overwhelming. Similarly, if together they imply more commercialization, it can be concluded that the effect of the property right dominates.

4.4 Estimation Results

4.4.1 Linear Probability Model

Results of the linear probability model are given in Table 4.5. Coefficients and asymptotically unbiased t-ratios are separately reported.

Four equations with slightly different specifications are presented. It is assumed for equation 1 that the underlying relationship between the probability of a spin-off and age of the firm is non-linear. Equation 2 constrains this relationship to a linear form. Equation 3 allows for non-linearity in both age and the proportion of total R&D that is contracted with the government, while equation 4 considers only the latter to be non-linearly related to the probability of a spin-off. As discussed above, the

property right variable, RY, incorporates the effects of property rights assignment and cost-sharing. Therefore, the estimated value of RY represents their net influence on the probability of a contract realizing a commercial spin-off.

Contractor retention of property rights appears to be unambiguously stimulative to commercial exploitation. In all four equations, the property right variable, RY, has a positive and significant coefficient, reflecting the strong and overwhelming effect of commercial rights on the commercialization effort and the likelihood of a spin-off. When the government relinquishes the right to technology and information developed under contract, the probability of a spin-off increases by 0.36 to 0.53.

As an example, consider an R&D contract awarded to a large Aircraft manufacturing firm. The contract was to develop technological improvements in gas generator turbines, leading to more energy efficient designs. The total value of the contract was 270,000 dollars, and the property rights for technologies developed were vested with the contractor. Given the attributes of the contractor and the contractual agreement, the probability of such a contract generating commercial spin-offs is estimated at 0.68. If the government had retained the rights, the predicted probability of a spinoff diminishes completely to 0.00.

As expected, the variable representing an unsolicited contract has a positive coefficient, and the associated t-statistic shows that it is significant at the 99 percent confidence level for a two-tailed test. This is consistent with the Mansfield and Switzer (1985) finding that, the greater the input of the contractor in the formulation of the R&D project, the greater the likelihood of a contract realizing commercial benefits.

Table 4.6 summarizes the model's prediction regarding the impact of the property right variable and the unsolicited proposal variable given that other variables are held constant.

Table 4.6

Probability of a Spin-Off: Property Right and Unsolicited Contract

		No	Yes
Property Right	No	0.00	0.26
	Yes	0.68	0.94

NOTE: Estimates based on equation (4).

Holding other variables constant, the joint effect of the unsolicited proposal variable and the property right variable is quite large. If, for example, the project is privately rather than government initiated, and the rights to the technology and/or information generated under contract are vested with the contractor, the likelihood of a commercial spinoff would increase from 0.68 to 0.94.

Consistent with the hypothesis, the probability of a spinoff is significantly lower when the performing firm has idle R&D personnel and/or facilities at the time of the contract. The regression coefficient for IDLE is statistically significant at the 99 percent confidence level for a two tailed test.

If the government has relinquished the rights to innovations developed under contract, the likelihood of the results being commercially exploited is smaller, all else being equal, if the contract utilizes personnel and facilities which otherwise would have been idle (see Table 4.7).

Table 4.7

**Probability of a Spin-off: Idleness, Foreign Ownership
and Government Benefits**
(property rights vested in the contractor)

	NO	YES
1. R&D Resource Idleness	0.68	0.15
2. Foreign Ownership (greater than)	1.0	0.68
3. Government Benefits Realized	0.68	0.72

NOTE: Probability estimates are based on equation (4)

Empirical evidence indicates a U-shaped relationship between the likelihood of a contract generating R&D results which are commercially utilized and the proportion of total R&D expenditures financed by the government. The RTSQ variable introduced to control for nonlinearities performs consistently and significantly. The probability of a spin-off falls initially as the extent of contract R&D increases, and after a certain point, the likelihood of a spin-off increases with greater government involvement (in terms of higher proportion of contract R&D to total R&D). The probability reaches a minimum value at an intermediate mix (around 50-60 percent).

Contrary to prior expectations, the age of the corporation, AGEQ, has a negative and significant coefficient which implies that older firms (in terms of number of years since incorporation to the contracting year) are less likely to realize commercial spinoffs. When the non-linearity in age is investigated, the coefficient of the non-linear term, AGESQ, is also negative, however, statistically insignificant.

In so far as the field of technology is concerned, the regression coefficient for the dummy mode variable depicting Rail and Surface Transportation Technology (denoted as RM2) has a positive sign and is marginally significant. The implication here, is that government contracts have a higher likelihood of realizing a commercial spinoff when the objectives of the projects are well-defined and the ultimate users are readily identifiable. The air transportation mode variable (RM3) has a negative and marginally significant coefficient.

In accordance with expectations, the probability of a spinoff is greater, the larger the number of patents granted to the firm. This implies that corporations which appreciate the benefits of patent protection over their commercial products and/or processes, and corporations with a relatively more successful R&D establishment, are more likely to realize commercial benefits when performing R&D work for the government.

The size of the firm variable (REV) measured in terms of total revenue in the contracting year, receives strong positive statistical support, reflecting the ability of larger firms to reap greater rewards of innovation, and perhaps, reflecting the greater likelihood that some R&D output will find a use because of greater diversification.

The estimated coefficient of the foreign ownership variable is negative and significant, implying that contracts with foreign owned firms have a smaller probability of yielding commercial benefits, holding all other variables constant. To the extent that foreign companies carry out most of their commercial R&D at the corporate headquarters away and separated from the Canadian R&D laboratory, this evidence supports the contention that proper coupling between commercial and government research is essential in

the commercialization of contract technologies. If there is good interaction between government and commercial R&D activities as is assumed for domestic firms, the probability of a spin-off would increase substantially (Table 4.7). There appears no discernible relationship between the realization of commercial benefits and the realization of government benefits.

Neither the size of the contract, CONTC, nor the time lag since project completion, CLAG, appear to be important determinants of commercial spin-offs. There is therefore no reason to favour the use of small over large R&D contracts. As allowing for greater exploitation time does not seem to enhance the likelihood of commercialization, commercial possibilities are most likely exploited immediately.

The data shows no support for the hypothesized positive association between the likelihood of a spinoff and the incidence of a firm being in the industrial sector (MANF). This could suggest that the additional licensing and other related costs that a service firm must incur before R&D results can be commercialized, are not significantly large to perversely affect commercialization.

While the results vary slightly from equation to equation depending upon the explanatory variables included, a number of robust general tendencies emerge. As far as the contractor specific variables are concerned, results indicate that the probability of a spinoff increases significantly where the contracting firm is: younger (in terms of years in business);

larger (in terms of revenues); domestically owned; and where operating R&D personnel and facilities are fully employed at the time of the contract. In addition, the greater the firm's innovative ability (measured by the number of patents received) the greater the likelihood of commercial benefits. Moreover, the probability that commercial benefits will be realized rises substantially if the R&D operation of the firm is either very commercially oriented or very government oriented.

Unsolicited proposals are positively associated with the incidence of a spin-off. This offers great intuitive appeal since privately initiated projects are expected to contain, amongst other things, more commercially oriented (and market sensitive) technologies than government initiated projects. This seems to be consistent with the results of Mansfield and Switzer (1985), Arthur D. Little (1976) and SRI International (1976).

A major finding is the impact of property rights assignment on the probability of a spinoff. The probability that commercial benefits will be realized increases significantly when property rights are assigned to the contractor. This is consistent across all four equations.

The overall model performance offers a significant degree of confidence. Examining the F-statistics, all equations are significant at the 0.05 critical level. On the basis of McFadden's R^2 and Akaike Information Criteria, the performance of equation 4 dominates all other equations.

4.4.2 Logit Model

Consider next the regression coefficients estimated from a logistically specified function. Table 4.8 presents two equations which are considered to give the best fit. Since the specific regression package employed

Table 4.8

Probability of a Contract Realizing Commercial Spin-offs
(Logistic Probability Model) *

INDEPENDENT VARIABLES	β	β	η	β	β	η
	(t-stat)	P(1-P)		(t-stat)	P(1-P)	
CONSTANT	-28.300 (-1.42)			-28.164 (-1.67)		
RY	58.455 (1.22)			68.456 (1.68)		
RW	43.425 (1.29)			48.299 (1.69)		
MANF	-6.1337 (-1.51)			-3.1099 (-0.90)		
AGEC	-1.6579 (-1.17)	-0.38	-37.48	-1.9717 (-1.65)	-0.45	-44.56
FOR	-44.225 (-1.08)			-54.495 (-1.59)		
REV	0.204E-07 (0.98)	0.046E-07	0.006	0.264E-07 (1.53)	0.06E-07	0.008
RM2	54.128 (1.29)			61.276 (1.72)		
IDLE	-27.251 (-1.53)			-27.297 (-1.80)		
FP	0.83 (1.17)	0.19	9.31	0.97468 (1.63)	0.22	10.94
DG	12.918 (1.65)			9.3505 (1.47)		
CONTC	0.187E-04 (1.18)	0.04E-04	2.52	0.156E-04 (1.31)	0.04E-04	2.10
CLAG	0.99624 (1.73)	0.23	1.73	--	--	--
Likelihood Ratio Test (d.f.)	38.1108 (12)			34.6056 (11)		
McFadden R ²	0.735			0.668		
AIC	19.84			20.60		
Proportion Correct Predictions	0.925			0.90		

by Statistics Canada does not as yet have the logit estimation procedure, the equations were estimated elsewhere, and as such, confidential variables, namely RCONT and RTSQ were not included. In addition, the firm's revenue in 1978 rather than in the year of the contract was used as a proxy for size. Admittedly, omitting some variables biases the results, and makes coefficient comparison more difficult. Nonetheless, findings based on the logit model should give further insights into the sensitivity of the results to alternative specifications.

Although RCONT and RTSQ were omitted, results obtained are generally similar to that of the linear probability model. The equations perform better generally when only RM2 is included (rather than both RM2 and RM3). Significant factors in determining commercial spin-off benefits include: (i) property right assignment; (ii) the unsolicited contract variable; (iii) the utilization of idle factors variable; (iv) age of the firm; and (v) the mode variable indicating R&D work in the area of Surface and Rail transportation. Marginally significant at the 95% confidence level for a one-tailed test is the average number of patents granted to the firm (FP). The relative effects of the explanatory variables on the probability of commercialization is provided by the respective t-ratios of the coefficients of the variables. The t-ratios of the coefficients in the linear probability model are invariably higher in absolute value, than those of the logit model.

Amongst the variables in the logit equations, property right seems to have the greatest effect on the probability of a commercial spin-off. The beta weight of the property right variable exceeds that of any other

variables. The effect of assigning property rights to the contractor on the probability of a spin-off is difficult to generalize. It is the property of the logistic functional form that the effect of each independent variable depends on the values of all independent variables.

By way of illustration, consider two R&D contracts. The first, a contract is awarded to an aircraft manufacturing company, and the right to exploit commercially technology conceived under contract is assigned to the company. Given the values of all independent variables, the predicted probability of a commercial benefit is 0.49187. In the absence of exclusive rights, the predicted probability would be reduced, virtually to zero. The second contract is awarded to a relatively small firm with no manufacturing capability. For this government-initiated contract, the property rights to contract technology belongs to the government. The predicted probability of the contract generating a commercial spin-off is zero. However, if property rights were assigned to the contractor, the probability would increase to 0.2872.

While the performance of each individual variable in explaining the probability value is not as strong as that of the linear model, the general results are quite similar. The likelihood ratio test (X^2 test) indicates that the variation in the dependent variable can be explained statistically by these factors taken as a group.

4.5 Conclusion

This chapter has attempted to provide some insight into the circumstances where a government R&D contract is likely to generate

spin-off benefits. A sample of Transport Canada R&D contracts was used to determine factors which have systematically influenced the probability of a commercial spin-off.

The problem was approached within the context of the profit maximizing model in which a contractor's choice involves the allocation of two types of R&D effort - contract specific and commercial activities. Contractual terms were assumed exogeneous and empirical relationships were hypothesized on this basis.

In many ways, the R&D contracting-out problem can be viewed as a principal-agent model with moral hazard. The principal is the government and the agent is a contracting firm. Moral hazard results from the fact that it is difficult to define and evaluate the quality or the innovative level of the R&D product and, that it is costly to directly observe the level of innovative effort of the contractor. The contractor can choose several avenues of research that affect the payoff to both firm and government. Since it is the contractor's action that ultimately determines benefits to the government, the interesting economic problem is to design a contract which provides the contracting firm with incentives to choose the optimal level of R&D effort and to choose the best avenues of research from the government's perspective (Cummins, 1977; McAfee and McMillan, 1985, 1987; Anton and Yao, 1987; Baron and Besanko, 1987; and Rogerson, 1988).

Our empirical findings can be summarized as follows. Commercialization is most closely associated with the assignment of property rights. The likelihood of direct commercial exploitation increases substantially when the contract technology is owned by the contractor. Since contractor's ownership of R&D results and R&D cost-sharing occurred together, their separate influence could not be determined statistically, and only the

equilibrium effect can be observed. The net positive and significant influence indicates that the positive effect of the property right variable outweighs the negative effect of the cost-sharing variable. Contracts originated in the private sector have higher probabilities of realizing commercial benefits. The probability that a contract generates commercial spin-offs is greater when the contractor is a new, domestically owned firm, with a relatively large annual sales. There is no persuasive evidence of more prolific commercial exploitation for R&D performing firms with manufacturing capabilities. The incidence of a commercial exploitation is higher when scientific and technical resources absorbed by the contract would otherwise have been fully employed. This suggests that there is a trade-off between higher commercial benefits and a lower R&D resource cost. Firms with a proven innovative capability (in terms of patents received) are also on average more successful at commercializing government funded R&D results, all else being equal. Finally, the incidence of commercialization is higher amongst firms with either a very small or a very large proportion of R&D financed by the government. Firms with approximately 60 percent government-financed R&D have the smallest probability of realizing commercial spin-offs, all other factors being equal.

ENDNOTES

1. See also R. Nelson, M. Peck and E. Kalachek (1967), Technology Economic Growth and Public Policy, The Rand Corporation and the Brookings Institution, pp. 83-86.

2. Research and Development Contracts normally state that:

"All designs, technical reports, photographs, drawings, plans, specification, models, prototypes, patterns and samples produced by the Contractor in the performance of the work shall vest in and remain the property of Her Majesty, and all other property produced or required by the Contractor in any manner in connection with the work and the cost of which is paid by Her Majesty shall rest in or remain the property of Her Majesty and the Contractor shall account fully to the Minister in respect of the foregoing in such manners as the Minister shall direct". (DSS 1036)

Furthermore...

"Unless otherwise provided in the contract, all technical information, inventions, methods and processes conceived or developed or first actually reduced to practice in carrying out the contract shall be the property of Her Majesty and shall be fully and promptly disclosed in writing to Her Majesty by the Contractor, and the Contractor shall have no rights in and to the same except such rights therein as may be granted by Her Majesty and shall not apply for any patent in regard thereto without Her Majesty's written consent. The Contractor shall not, without the written consent of Her Majesty, divulge or use such technical information, inventions, methods and processes other than in the carrying out of the work, and, in particular, shall not sell other than to Her Majesty and articles or things embodying such technical information, inventions, methods and processes or grant any license to manufacture such articles or things without the written consent of Her Majesty."

3. Furthermore, the government is granted a non-exclusive license to use any relevant background patents owned or controlled by the contractor provided that the government reasonably compensates the contractor. In the event that the contractor chooses not to apply for a patent, all rights are assigned to the government and the government can then file for a patent.

4. When a contractor absorbs part of the R&D costs, the government should make the contracting package more attractive by conferring ownership to technologies developed under contract to the contractor. Then, the statements of the government project officers are not inconsistent with the equilibrium of the model.
5. The classification of firms is based on the Standard Industrial Classification Code (SIC).

Chapter 5

Commercial Benefits and Property Rights: A Simultaneous Equation Model

5.0 Introduction

It is reasonable to expect that the incidence of a spinoff and the incidence of a contract vesting property rights with the contractor are determined jointly. This is because the incentive to innovate depends in part upon the assignment of rights to research results, and conversely, the decision to negotiate for exclusive rights, is dependent upon the expectation of discovering technology or knowledge that may be commercially useful. Provided that property right is alienable the empirical model can then be formulated as a system of simultaneous equations. This chapter examines the factors that determine the probability of a contract realizing a commercial spinoff, with the assumption that the disposition of patent rights is determined endogeneously.

Little systematic analysis has been done on the incidence of a firm acquiring exclusive rights to R&D results developed under contract. Earlier studies on attitudes towards property rights have concentrated mainly on variables that influence a firm's propensity to patent, and have focused principally on commercial R&D (Scherer, 1965, 1983; Mansfield et al., 1968; Comanor and Scherer, 1969; Rosenberg, 1974; Stoneman, 1979; Mansfield, 1986; and others).

In Canada, R&D contracts are generally governed by the DSS1036 provision which vests all rights with the government. The Science Council of Canada (1976) quotes some of the firms' principle concerns over DSS1036 as follows:

"... since there is no exclusivity... A company could develop the product and the market and theoretically another company could walk in with equal status."

and

"With contracts the government wants to access the total of the expertise we have developed over the years, at our own expense. They want the full rights to the knowledge and technology which is embodied in whatever material is transferred under the terms of the contract. In principle the government may turn around and go to one of our competitors with the information. There is nothing to stop them. (pp. 345-346).

The study concludes that:

"... firms do not automatically receive exclusive right to any products developed through government contracts. Since firms normally invests its accumulated expertise and know-how in development contracts - that is, the real cost of the R&D is considerably greater than the immediate cost of the work - it can feel cheated of its unique and costly assets if a product developed under a contract is then transferred to another company for manufacturing." (p. 346)

The absence of exclusive commercial rights may preclude some but not all firms from actively participating in government contracts. A firm's lack of interest in exclusivity may be due to perceived low commercial opportunities, or because the firm is not in a position to appropriate the secondary benefits that may arise.

How important are exclusive rights to the contractors? What factors affect the likelihood that a firm will negotiate for patent rights to technology or information developed under contract? In order to explain the variation in attitudes towards property rights, a regression analysis, relating the incidence of a contract vesting patent rights with the contractor, to firm specific characteristics, and to the anticipation of commercial benefit is undertaken.

5.1 Simultaneous Equation Model

The probability that a firm j will negotiate for and obtain patent rights to innovations emanating from the i^{th} contract (RY_{ij}) is assumed to depend on:

$$RY_{ij} = f(P_{ij}, \pi_j)$$

where P_{ij} is the j^{th} firm's expectation of commercial benefits from the i^{th} contract, and π_j is the profitability of exclusive commercial rights. The variable π_j is assumed to depend on the nature, size, ownership, and age of the firm, as discussed below.

(1) Nature of the Firm (NOPAT, MANF, and RCONT)

Harbridge House (1968) investigated the attitudes of U.S. contracting firms towards patents on government sponsored inventions. They found that research firms that did a relatively large percentage of their business with the government, typically attached no significance to patent rights. Some firms viewed patent protection as secondary to the technical knowledge acquired through performing the contract research. These were typically firms with manufacturing capabilities who engaged in the production of complex products and processes.

Other firms felt that they could use patent protection to establish and maintain proprietary position in new product areas. These firms who viewed patents as essential to their business, normally ensured corporate ownership prior to working on the contract. They often designed their research operation such that commercial and government R&D were sufficiently separated to avoid possible conflicts over ownership.

A readily measurable variable that would partially reflect the firm's attitude towards exclusive rights is the patent stock of the contractor, defined as the number of patents received (NOPAT). This provides a crude

measure of the firm's past reliance on patent protection, and the extent to which proprietary knowledge is essential to its business activities. The variable is calculated, by taking the average of the number of patents taken out by the firm, for the series of years from 1977 to 1984. Transferred patents from foreign affiliates and parent firms are also included in the calculation. This information is available from The Canadian Patent Office Records, Department of Consumer and Corporate Affairs. A positive relationship is expected between the average number of patents taken out by the corporation and the incidence of a contractor retaining rights to research results.

The second variable is the manufacturing capability of the contractor (MANF). As previously argued, it may be easier for a manufacturing firm to exploit the fruits of R&D results as additional licensing and related costs would not be incurred for commercialization. In this way, a manufacturing firm may find exclusive rights more valuable.

The third variable is the proportion of R&D financed by the government (RCONT). This will demonstrate whether or not a contractor who has a large fraction of their R&D business with the government is likely to show significant interest in patent protection. In order to allow for possible nonlinearities in the underlying relationship, the squared term (RTSQ) is also included.

(2) Firm Size: (REV)

A number of analysts have attempted to determine whether patent protection tends to be more important to smaller firms than to larger ones (Scherer, 1965; Mansfield, 1968, 1981; Comanor and Scherer 1969; Rosenberg 1974; Stoneman 1979; and others).

The incentive to acquire principle rights to technologies emanating from R&D contracts is thought to be stronger for larger firms, for the reason that appropriable benefits from proprietary ownership are likely to be larger because of their relatively large market shares. Therefore, a positive association is expected here.

(3) Foreign Ownership (FOR)

Since foreign owned firms are likely to have greater access to geographically different markets in which derivative technologies can be commercially exploited, they are likely to place greater significance on patent protection than domestically owned firms. A positive coefficient is therefore expected for the foreign ownership variable.

(4) Age of the Firm: (AGEC)

It is reasonable to suspect that older firms with more technical, commercial, and marketing experience would have a greater capacity to recognize and exploit any technological fall-out. Consequently, older corporations would be more likely to seek out exclusive ownership to any potential technology arising out of government contract R & D.

(5) Area of Technology (RM2 and RM3)

The need for exclusive right protection may differ systematically across areas of technology. In order to account for these inter-technology differences, two binary variables denoting Surface and Rail transportation, and Air transportation are included as explanatory variables.

Briefly, the system which endogenizes the firm's retention of patent rights and the incidence of commercial spin-offs consists of the following equations.

$$(1) \quad B_{ij} = f(RY_{ij}, DG_{ij}, RW_{ij}, RM2_{ij}, RM3_{ij}, IDLE_{ij}, MANF_j, REV_{ij}, \\ FOR_j, RCONT_{ij}, AGE_{ij}, FP_j, CONTC_{ij}, CLAG_{ij})$$

$$(2) \quad RY_{ij} = g(P_{ij}, NOPAT_j, MANF_j, RCONT_j, REV_{ij}, FOR_{ij}, AGE_{ij}, \\ RM2_{ij}, RM3_{ij})$$

where P_{ij} = Probability that the i^{th} contract to the j^{th} firm realizes commercial benefits.

RY_{ij} = 1 if contractor retains property rights
0 otherwise

DG_{ij} = 1 if contract realizes government benefits
0 otherwise

RW_{ij} = 1 if unsolicited contract
0 otherwise

$RM2_{ij}$ = 1 if technology is in Surface and Rail
0 otherwise

$RM3_{ij}$ = 1 if technology is in Air
0 otherwise

$IDLE_{ij}$ = 1 if contract employs resources which otherwise would have been idle
0 otherwise

$MANF_j$ = 1 if the contractor is a manufacturing firm
0 otherwise

REV_{ij} = firm size (revenue of the firm the contracting year)

FOR_j = 1 if the contracting firm is foreign owned
0 otherwise

RCONT_{ij} = proportion of total R&D performed financed by the government in the contracting year

AGEC_{ij} = age of the firm (years since incorporation) at the time of the contract

FP_j = average number of patents of the firm (patent stock)

CONTC_{ij} = size of the contract

CLAG_{ij} = number of years since the completion of the R&D contract to the year of analysis, 1984

NOPAT_{ij} = total number of patents including patents received from subsidiaries and affiliates

5.2 Estimation Methods

This section discusses two estimation techniques appropriate for simultaneous equation models with non-continuous (catagorical) endogenous variables. Two different specifications are explored - a Linear Probability model and a Logistic Probability (LOGIT) model.

Heckman and McCurdy (1985) proposed a technique for estimating simultaneous models with limited dependent variables. Their approach uses the linear probability model and allows analysts to use familiar methods to distinguish between spurious and causal association between discrete endogeneous variables.

The second is the simultaneous logit model, introduced by Maddala and Lee (1976). While the logistically specified model is theoretically more desirable than the linear probability model, the interpretation of parameter estimates are more difficult. Because of its functional form,

the marginal effect of a variable on probability, depends upon the values of all other exogenous variables. Wu (1973) test is used as a test of exogeneity in the above simultaneous equations models.²

5.2.1 Simultaneous Linear Probability Model

Heckman and MaCurdy (1985) examined simultaneous equations estimation problems involving endogenous variables, which are assumed to be categorical. They derived a model which estimates relationships amongst jointly determined endogenous discrete variables, and gives the probability of an event occurring. Heckman and MaCurdy's method is described below.

Consider a two-equation simultaneous system where the first structural equation can be written as

$$y_1(i) = \tau_1 y_2(i) + \sum_{j=1}^{K_1} \beta_{1j} X_{1j}(i) + u_1(i),$$

and the second equation

$$y_2(i) = \tau_2 y_1(i) + \sum_{j=1}^{K_2} \beta_{2j} X_{2j}(i) + u_2(i),$$

where X_{1j} and X_{2j} are the j^{th} exogenous variable in equation one and two respectively, and $u_1(i)$ and $u_2(i)$ are associated error terms. X_{1j} and X_{2j} are vectors of exogenous variables representing attributes of the contractor and contract as well as other characteristics related to the project. β_{1j} 's and β_{2j} 's are unknown parameters to be estimated for equation 1 and equation 2. τ_1 and τ_2 are unknown parameters for the endogenous variables y_2 and y_1 respectively.

Provided that standard rank and order conditions for identifiability are satisfied, the system can be estimated using either instrumental variables or two stage least squares (2SLS). Excluded variables in X_1 can be used as instruments for y_2 and similarly, excluded variables in X_2 can be used as instruments for y_1 . In the common 2SLS, the reduced form is generally obtained by estimating the relationship between the right hand side endogenous variable and the set of all exogenous and predetermined variables in the model.

Ideally, the appropriate endogenous variables in the proprietary rights equation should be the expectation of commercial benefits associated with the R & D contract in question. However as the direct measure of this latent variable is not available, the actual event of commercialization is used as a surrogate. Therefore contractors are assumed rational regarding their expectation of commercial opportunities.

A single-equation estimation involves a simple application of the familiar 2 stage least squares method to a simultaneous equations system with heteroskedastic errors. For significance tests, the asymptotically consistent standard errors for the estimator are generated based on White (1982) and Eicker (1963, 1967) procedures.

Heckman-MaCurdy's (1985) least squares estimation technique involves a 3-step procedure. Step 1 is the estimation of the two structural equations by two stage least squares. This provides consistent estimates for γ_1 and γ_2 , unknown coefficients of the endogenous variables. Step 2 is the generation of the estimated values of the residual terms $u_1(i)$ and $u_2(i)$, using estimates from step 1.

$$\hat{u}_1(i) = y_1(i) - \hat{y}_1(i) = y_1(i) - \hat{\gamma}_1 y_2 - \sum_{j=1}^{K_1} \hat{\beta}_{1j} x_{1j}(i)$$

$$\hat{u}_2(i) = y_2(i) - \hat{y}_2(i) = y_2(i) - \hat{\gamma}_2 y_1 - \sum_{j=1}^{K_2} \hat{\beta}_{2j} x_{2j}(i)$$

Finally, in step 3, Ω_{11} and Ω_{12} matrices are generated, where i subscript is the equation notation, $i = 1, 2$

$$\Omega_{11} = \begin{bmatrix} \sum \hat{Y}_1(i) \hat{Y}_1'(i) & \sum \hat{Y}_1(i) X_1'(i) \\ \sum X_1(i) \hat{Y}_1(i) & \sum X_1(i) X_1'(i) \end{bmatrix} (1/I)$$

$$\Omega_{12} = \begin{bmatrix} \sum \hat{Y}_1(i) \hat{u}_1^2(i) \hat{Y}_1'(i) & \sum \hat{Y}_1(i) \hat{u}_1^2(i) X_1'(i) \\ \sum X_1(i) \hat{u}_1^2(i) \hat{Y}_1(i) & \sum X_1(i) \hat{u}_1^2(i) X_1'(i) \end{bmatrix} (1/I);$$

where I is the total number of observations. Heckman and MaCurdy (1985) showed that the distribution for the two stage least squares estimator is consistent and asymptotically normally distributed,

$$\sqrt{I} \begin{bmatrix} \tau(i) - \hat{\gamma}(i) \\ \beta(i) - \hat{\beta}(i) \end{bmatrix} \sim N(0, \Omega_1^{-1} \Omega_2 \Omega_1^{-1})$$

The change in the probability of an event occurring from a given change in x_j is determined by differentiating the structural estimated equation with respect to x_j . The marginal effect of X_{1j} on P_1 is represented by β_{1j} .

5.2.2 Simultaneous Logit Model

Maddala and Lee (1976) and Lee (1981) propose an uncomplicated method of estimating simultaneous logit equations. Formulated as a system of 2 simultaneous equations the model can be written as:

$$y_1(i) = 1 / [1 + \exp(-(\sum_{j=1}^{K_1} \beta_{1j} X_{1j}(i) + \tau_1 y_2(i) + u_1(i)))]$$

$$y_2(i) = 1 / [1 + \exp(-(\sum_{j=1}^{K_2} \beta_{2j} X_{2j}(i) + \tau_2 y_1(i) + u_2(i)))];$$

and can be easily transformed into a linear model by taking the logarithm of the odd ratio. It follows that

$$\tilde{y}_1(i) = \tau_1 \tilde{y}_2(i) + \sum_{j=1}^{K_1} \beta_{1j} X_{1j}(i) + \epsilon_1(i)$$

$$\tilde{y}_2(i) = \tau_2 \tilde{y}_1(i) + \sum_{j=1}^{K_2} \beta_{2j} X_{2j}(i) + \epsilon_2(i)$$

where $\tilde{y}$ denotes the log of the odd ratio of an event, and

$$\tilde{y}_1(i) = \log \left(\frac{y_1}{1-y_1} \right) \text{ and } \tilde{y}_2(i) = \log \left(\frac{y_2}{1-y_2} \right).$$

In vector and matrix notations, these can be written as

$$\tilde{y}_1(i) = \tau_1 \tilde{y}_2 + X_1 \beta_1 + \epsilon_1$$

$$\tilde{y}_2(i) = \tau_2 \tilde{y}_1 + X_2 \beta_2 + \epsilon_2$$

If the model is identified we can write the reduced form equations as:

$$\tilde{y}_1 = X_{11} \pi_1 + u_1$$

and

$$\tilde{y}_2 = X_{22} \pi_2 + u_2$$

Then

$$\hat{\tilde{y}}_1 = X_{11}\hat{\pi}_1 \text{ and } \hat{\tilde{y}}_2 = X_{22}\hat{\pi}_2$$

where X_{11} is a matrix of all exogenous variables in the model not included in the second structural equation, and X_{22} is a matrix of all exogenous variables not included in the first structural equation. These two reduced form equations are estimated by the logit maximum likelihood method. π 's are reduced form consistent estimates.

The structural parameter estimates are obtained from the second stage. Substituting in the reduced form equations,

$$\tilde{y}_1 = X_1\beta_1 + \tau_1\tilde{y}_2 + \epsilon_1 = X_1\beta_1 + \tau_1(X_{22}\pi_2) + \tau_1u_2 + \epsilon_1$$

$$\tilde{y}_2 = X_2\beta_2 + \tau_2\tilde{y}_1 + \epsilon_2 = X_2\beta_2 + \tau_2(X_{11}\pi_1) + \tau_2u_1 + \epsilon_2$$

Given that consistent estimates, π_1 and π_2 have been derived in the first stage, the structural parameters then can be obtained by estimating the structural equations .

$$\tilde{y}_1 = X_1\beta_1 + \tau_1(X_{22}\pi_2) + \omega_1 \text{ where } \omega_1 = \tau_1u_2 + \epsilon_1 + X_{22}(\pi_2 - \hat{\pi}_2)\tau_1$$

$$\tilde{y}_2 = X_2\beta_2 + \tau_2(X_{11}\pi_1) + \omega_2 \text{ where } \omega_2 = \tau_2u_1 + \epsilon_2 + X_{11}(\pi_1 - \hat{\pi}_1)\tau_2$$

using the maximum likelihood technique.

Differentiating the above equations with respect to X_j we have as in the single equation model.

$$\frac{\partial P_i}{\partial X_j} = \beta_j P_{i1} (1 - P_{i1}) \text{ for } i = 1, 2$$

The marginal effect of X_j on P_{11} varies as we move along the logistic curve. The marginal effects are traditionally computed at the mean value of p_i for the sample.

5.3 Empirical Results

5.3.1 Results: A Simultaneous Linear Probability Model

Results from the estimation of the structural equations for commercial spinoff and contractor property right retention by the Heckman-MaCurdy method are presented in Table 5.1. Consistent with expectations, the property right variable is statistically significant in the structural equation for commercial benefits, and the expected commercial benefit variable is also significant statistically in the structural equation for contractor retention of property rights.

The probability of a contract generating a spin-off is greater, all else being the same, if the contractor is new, relatively large and domestically owned, with an R&D operation which is either heavily oriented to government-financed research or heavily oriented to commercial research. The likelihood of a spin-off is also greater when the contractor's domestic patent stock is relatively large and when the contracting firm has no idle capacity. While no significant differences appear between the simultaneous equations and the single equation models (Chapter Four) in terms of the individual variable's explanatory power, the estimated coefficient of the patent right variable is almost twice as large when it is treated as endogenous.

Given the specification of the property right equation variables which are statistically significant include; as expected, the anticipa-

tion of commercial spinoffs; age of the firm; and the variables denoting systematic differences in the technological areas. Marginally significant is the proportion of total R&D funded by the government.

Table 5.2 presents another set of estimates. Since there appears to be no persuasive evidence of a non-linearity in the relationship between the proportion of R&D financed by the government and the incidence of property rights being retained by the contractor, RTSQ was subsequently excluded from the equation. With this alternative specification, the effect of the proportion of R&D funded by the government variable becomes considerably more significant statistically, all else remaining the same.

Since it is possible that there may be positive collinearity between foreign ownership and the average number of patents belonging to the firm, which includes transferred patents from subsidiaries and affiliated firms abroad, the model was reestimated omitting the foreign ownership variable from the property rights equation (Table 5.3). As table 5.3 indicates, the firm size variable is negative and significant statistically, implying that patent protection is more important to smaller contractors than to larger ones.

5.3.2 Results: Simultaneous Logit Model

Presented in Table 5.4 are the best estimates of the spin-off equation and the property right equation based on the Maddala and Lee's (1976) (and as reiterated by Lee in 1981) estimation procedure. It is worthwhile to note that two variables (RCONT and RTSQ) are excluded as they are confidential and are strictly available to Statistics Canada.

Table 5.1

**Estimation of Commercial Benefit and Property Right Equations
by Heckman-McCurdy Linear Probability Simultaneous Equations Method**

Probability of a Contract Realizing Commercial Benefits		
	β	t
CONSTANT	0.79581	2.29
RY	1.2554*	1.98
RW	0.20167*	1.68
MANF	-0.9159E-01	-0.29
AGEC	-0.2351E-01*	-3.80
FOR	-0.58124**	-2.94
REV	0.2755E-06**	2.88
RM2	0.38143*	1.87
RM3	-0.92715	-1.79
IDLE	-0.59137**	-2.74
RCONT	-1.6324**	-2.36
RTSQ	1.3683	1.93
FP	0.8869E-02*	4.18
DG	0.21309	0.70
CONTC	0.7277E-06	0.99
CLAG	0.42416E-01*	1.78

Probability of a Contract Assigning Patent Right to the Contractor		
CONSTANT	-0.42078	-3.28
P	0.32753*	1.84
RCONT	0.60159	1.68
RTSQ	-0.29437	-0.80
MANF	0.67755E-01	0.83
NOPAT	-0.4723E-02	-1.13
REV	-0.10913E-06	-1.55
FOR	0.13416	0.64
AGEC	0.11586E-01*	4.10
RM2	-0.20489	-1.82
RM3	0.71920**	3.39

* Variable significant at 0.05 level (one-tailed test)

** Variable significant at 0.05 level (two-tailed test)

Table 5.2

Estimation of Commercial Benefit and Property Right Equations
by Heckman-MaCurdy Linear Probability Simultaneous Equations Method

Probability of a Contract Realizing Commercial Benefits		
	β	t
CONSTANT	0.79581	2.32
RY	1.2554*	1.91
RW	0.20167*	1.68
MANF	-0.9159E-01	-0.28
AGEC	-0.23506E+01*	-3.79
FOR	-0.58124**	-2.90
REV	0.27549E-06**	4.77
RM2	0.38143*	1.86
RM3	-0.92715	-1.77
IDLE	-0.59137**	-2.74
RCONT	-1.6324**	-2.63
RTSQ	1.3683	1.87
FP	0.88688E-02*	4.18
DG	0.21309	0.70
CONTC	0.72771E-06	0.99
CLAG	0.42416E-01*	1.18
Probability of a Contract Assigning Patent Right to the Contractor		
CONSTANT	-0.39701	-3.17
P	0.31622*	1.80
RCONT	0.31986**	2.35
RTSQ	-	-
MANF	0.89954E-01	1.20
NOPAT	-0.46528E-02	-1.14
REV	-0.10416E-06	-1.50
FOR	0.12243	0.61
AGEC	0.11214E-01*	3.96
RM2	-0.20471	-1.80
RM3	0.70090**	5.82

* Variable significant at 0.05 level (one-tailed test)

** Variable significant at 0.05 level (two-tailed test)

Table 5.3

**Estimation of Commercial Benefit and Property Right Equations
by Heckman-MaCurdy Linear Probability Simultaneous Equations Method**

**Probability of a Contract
Realizing Commercial Benefits**

	β	t
CONSTANT	0.79581	2.29
RY	1.2554*	1.90
RW	0.20167*	1.69
MANF	-0.9159E-01	-0.29
AGEC	-0.2351E-01*	-3.89
FOR	-0.58124**	-2.61
REV	0.27549E-06**	5.00
RM2	0.38143*	1.87
RM3	-0.92715	-1.73
IDLE	-0.59137**	-2.76
RCONT	-1.6324**	-2.43
RTSQ	1.3683	1.93
FP	0.8869E-02*	3.87
DG	0.21309	0.70
CONTC	0.7277E-06	0.98
CLAG	0.42416E-01	1.17

**Probability of a Contract
Assigning Patent Right to the Contractor**

CONSTANT	-0.39201	3.32
P	0.30524*	1.78
RCONT	0.56550	1.58
RTSQ	-0.28098	0.77
MANF	0.70319E-01	0.86
NOPAT	-0.20956E-02	-1.21
REV	-0.75434E-07**	-2.23
FOR	-	-
AGEC	0.10670E-01*	4.45
RM2	-0.19247	-1.81
RM3	0.71403**	5.87

* Variable significant at 0.05 level (one-tailed test)

** Variable significant at 0.05 level (two-tailed test)

Table 5.4

Estimation of Commercial Benefit and Property Right Equations
by Simultaneous Logit Model

Probability of a Contract Realizing Commercial Benefits		
	β	t
CONSTANT	-7.3586	-1.53
RY	1.4309	1.21
RW	11.107	1.62
MANF	-1.3288	-0.48
AGEC	-0.14401	-1.72
FOR	-3.5588	-0.70
REV	-0.8828E-09	-0.27
RM2	9.2918	1.78
IDLE	-10.447	-1.80
FP	0.093096	1.58
DG	4.2322	1.00
CONTC	0.11254E-04	1.56
CLAG	1.1430	1.83
-2 log likelihood ratio 30.86 12 df		
Probability of a Contract Assigning Patent Right to the Contractor		
	β	t
CONSTANT	-16.676	-0.96
P	-0.28866	-0.40
NOPAT	0.01723	0.22
MANF	0.99325	0.16
REV	0.12751E-08	0.60
AGEC	0.15021	1.44
RM2	0.66688	0.05
RM3	10.990	0.71
-2 log likelihood ratio 39.31 7df		

As indicated by the likelihood ratio test (Table 5.4), the probability of a contract realizing a commercial spin-off can be explained by the independent variables included as a group. However, individually the explanatory variables are not statistically significant. Similarly, while the probability of a contract vesting property rights with the contractor can be explained by the model as a whole, the model cannot isolate the independent effect of each regressor.

In comparison, the linear probability model appears to have performed better than the logit probability model. One possible reason is that with this logit specification, the probability values might be inappropriately restricted to lie along the S-shape logistic curve. Another reason may be related to the omitted variables, RCONT and RTSQ. Whatever the reason, the evidence obtained suggests that results are not invariant to specification.

5.4. Conclusion :

In this chapter we extend our empirical analysis as presented in Chapter Four, to take into account the possible simultaneous relationship between the probability of a commercial spin-off and the probability of the contract vesting property rights with the contractor. Two recently proposed estimation procedures designed specifically for non-continuous endogenous variables are useful for this purpose. On the basis of Wu's specification test, it is appropriate to employ the suggested simultaneous estimation techniques. Given the specifications of the equations in this model, the main results obtained are summarized below.

The empirical evidence indicates that patent rights are essential to the contractor's commercialization of government R&D results. The pro-

bability of a contract realizing commercial benefits is greater when the contractor is a large, new, and domestically owned firm which has no excess R&D capacity. Commercial spin-offs are also more likely when the contract is unsolicited, and research ideas originally formulated by the contractor. Firms with a relatively more productive research operation (relatively large domestic patent stock), and a large proportion of self-financed R&D, commercially exploit government R&D results more often, all else being the same.

Our statistical results indicate that the probability of a contract vesting property rights with the contractor is greater when the contractor is an old and a relatively small firm. The proportion of government financed R&D to total R&D variable is marginally significant and positively related to patent right variable. The probability of a contract conferring property rights to the contractor is greater where spin-offs are expected. The spin-off variable is statistically significant at the 95 percent confidence level for a one-tailed test.

A possible extension of this study is to respecify the property right equation by incorporating other explanatory variables, and examine the sensitivity of the results to alternative specifications. This, however must be done with a different data set. Future analysis of R&D contracting-out and contract outcomes might usefully investigate further how the terms of a contract which does not grant patent rights to the contractor, differ from those in a contract granting rights to the contractor. Of course, this would require a more complete analysis of the entire contracting package including contract awarding mechanisms and R&D cost-sharing arrangements. Presumably, in the absence of patent rights, the package must be made more attractive to the bidders and premiums must be provided elsewhere.

ENDNOTES

1. Harbridge House (1968), Government Patent Policy Study (Boston, Mass: U.S. Government Publication).
2. Nakamura and Nakamura (1981) showed that Wu (1973, 1974) and Hausman (1978) tests are equivalent. Under the alternative hypothesis $H_A: \text{Cov}(X_1, e) \neq 0$ OLS estimate is inconsistent and 2SLS estimate is consistent. Wu's test requires a comparison between an Ordinary Least Squares estimate and a 2SLS estimate. The standardized difference follows a X^2 -distribution. See Wu (1973), "Alternative Tests of Independence Between Stochastic Regressors and Disturbances", Econometrica 41(3), 1973 pp. 733-50, and Ruud (1984), "Test of Specification in Econometrics", Econometric Review, 3(2) pp. 232-237.
3. Of course, the interpretation has the same caveat as before. That is, commercialization might be related to the contractor's prior knowledge and information.

Chapter 6

Direct Government Benefits

6.0 Introduction

While there has been a lot of discussion regarding costs to the government associated with contracting out, most of this has focused on the explicit costs of conducting R&D, and little or no attention has been given to the opportunity costs, i.e., the costs associated with the lower likelihood that the government achieves its mission oriented objectives. Contracting out policy is intended to meet government R&D requirements while at the same time generating additional private benefits to the non-government sector through commercial exploitation of spillover knowledge or technologies. By placing the government's research work in the hands of those who have greater pecuniary incentives, it is believed that contracting-out will enhance the probability of commercial exploitation of research results. When contractors can benefit commercially from the product, process or technical information resulting from contracted R&D, they would have greater incentives to maximize all opportunities for turning research results into commercial advantage. This, however, may be done at the expense of government research objectives.

This chapter examines the trade-off between the realization of commercial benefits and the achievement of government research objectives.

It addresses the following questions; 1) What are the factors that influence the probability of an R&D contract leading to the development of a new or improved product, process or of technical information which can be used directly by the federal government or its agencies? and; 2) Is the

likelihood of the government utilizing R&D results perversely affected by commercial opportunities?

This chapter commences with a model which demonstrates the potential trade off between the realization of government (a_g) and commercial (a_c) benefits. The following two sections present respectively an empirical model and some statistical findings.

6.1 Relationship between Government Benefits and Commercial Benefits

The motivation behind the following model is the idea that a contracting firm has a choice of either (i) exploiting fully the commercial opportunities of a given R&D contract and delivering the minimum quality on the government needed R&D or, (ii) foregoing some commercial objectives and delivering to the government superior quality R&D. A firm may wish to deliver a superior product in order to capture rents from future government contracts. These rents may take the form of a greater likelihood of winning a government contract even with a less competitive price, a greater chance of being sought out and selected as a sole source R&D performer, or, a greater probability of having an unsolicited R&D proposal accepted. A firm which chooses to provide lower quality R&D on the immediate contract may be less likely to be awarded profitable future government R&D contracts.

Consider a contractor engaging in two types of revenue generating activities. Revenue from delivering government R&D, $R(q_g)$, is the discounted value of expected future rents from follow-on government R&D contracts. Revenue from commercial R&D is denoted by $V(q_c)$. The proportion of the commercial revenue directly appropriable by the contractor is given by the variable θ . The cost of producing q_g and q_c is summarized by the

joint cost function $C(q_1, q_2)$. The ability to generate government and commercial research output, q_1 and q_2 , respectively, is constrained by the firm's R&D resources. Total research potential is limited to a fixed amount k , where $q_1 + q_2 = k$. A firm's profit function can then be represented as

$$\pi = R(q_1) + \theta V(q_2) - C(q_1, q_2) + \lambda(k - q_1 - q_2) \quad (1)$$

where $R(q_1)$ = revenue function from delivering government R&D of quality exceeding that required by the contract

$V(q_2)$ = revenue function from commercial R&D

θ = appropriability or property right variable $0 \leq \theta \leq 1$

$C(q_1, q_2)$ = cost function of producing q_1 and q_2

It is assumed that $R(q_1)$ and $V(q_2)$ are continuous and concave, with $R_{q_1}, V_{q_2} > 0$ and $R_{q_1 q_1}, V_{q_2 q_2} < 0$. Also, C_{q_1} and $C_{q_2} > 0$, and $C_{q_1 q_1}, C_{q_2 q_2} \geq 0$.

A contracting firm's decision is to choose the amount of q_1 and q_2 such that the firm's profit is maximized. The first order conditions for profit maximization are given by

$$\frac{\partial \pi}{\partial q_1} = R_{q_1}(q_1) - C_{q_1}(q_1, q_2) - \lambda = 0 \quad (2.a)$$

$$\frac{\partial \pi}{\partial q_2} = \theta V_{q_2}(q_2) - C_{q_2}(q_1, q_2) - \lambda = 0 \quad (2.b)$$

$$\frac{\partial \pi}{\partial \lambda} = k - q_1 - q_2 = 0 \quad (2.c)$$

The economic interpretation of the necessary conditions is straightforward. The contractor will choose q_1^* , the optimal amount of government

R&D, by equating the marginal revenue to the marginal cost of providing one more unit of q_1 . Similarly, the contracting firm will try to exploit commercial opportunities and try to turn contracted research into commercial advantage up to the point where the marginal revenue appropriable from commercialization activity is equal to the marginal cost of developing the product to a commercial standard.

The second-order conditions require that the determinant of the matrix

$$\begin{bmatrix} R_{q_1, q_1} & -C_{q_1, q_1} & -C_{q_1, q_2} & -1 \\ -C_{q_2, q_1} & V_{q_2, q_2} & -C_{q_2, q_1} & -1 \\ -1 & -1 & & 0 \end{bmatrix} = \Delta$$

be positive when evaluated at the optimal q_1^* and q_2^* .

The question as to how government research is influenced by the firm's ability to benefit from commercial venture can be examined in the above context by using Cramer's Rule. It can be shown that

$$\frac{dq_1}{d\theta} = \frac{-v_{q_1}}{|\Delta|} < 0 \quad (3.a)$$

and similarly

$$\frac{dq_2}{d\theta} = \frac{v_{q_2}}{|\Delta|} > 0 \quad (3.b)$$

The first comparative static result shows that the greater the commercial benefits to the contracting firm, the smaller the R&D benefits to the government. The second comparative static result shows that if the extent

to which a contractor can benefit commercially from an R&D contract is increased, then the amount of effort devoted to commercially oriented R&D activity will increase. This indicates that the likelihood of commercial benefits increases unambiguously with increased appropriability. The essential point here is that, other variables being constant, the incidence of a contract generating government benefits is negatively related to the contract's commercial opportunities.

6.2 Empirical Model

In this section, the paper attempts to empirically isolate variables which will help to discriminate between contracts which generate government benefits and others that do not.

Direct government benefits are defined to have occurred when a contract has resulted in the development of a new or improved product, process or of technical information which was used by the federal government or its agencies.

Since there is no measurement process to indicate the importance of R&D results to the government, and no established quantitative yard sticks to provide readings of the government's utilization of the research results, project officers were asked to assess whether information or technology developed under specific contracts was utilized by the government. This direct government benefit variable takes on a value of 1 in the case where utilization occurred, and zero otherwise. A contract was defined to have entailed no direct government benefits if either its research objectives had not been met or if they had been met but the results had not been used directly by the federal government. In the opinion of the project

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officers, benefits of this nature had been realized in 60 percent of the contracts examined.

It is important to emphasize that the absence of "government benefits" does not necessarily imply that the government was cheated of its research value, nor does it suggest that project officers should pursue other contracting means for R&D. Unless more detailed information is available on the expected value of the research work, the price and terms of the contract, and the method of awarding the contract, it would be difficult to determine with any significant degree of confidence whether the contract outcome is in accord with the contract price. The absence of government benefit may be consistent with lower contract price.

From equation (3.a), it is clear that there is a direct trade-off between government and commercial benefits when there is a constraint on the R&D resources and thereby on the production of the two research outputs, q_1 and q_2 . However, when there are idle R&D resources, commercial opportunities do not necessarily imply reduced government benefits. Hence, trade-offs between government and commercial benefits are expected only when an R&D contract causes congestion in the firm's R&D operation.

In order to determine whether there is resource congestion, contractors were asked to respond to the question: did the R&D contract utilize R&D personnel and/or facilities which otherwise would have been idle? A "no" answer would imply that the R&D contract caused congestion. (See chapter 3 for a detailed description of the survey on R&D resources.)

To empirically isolate factors which influence the probability of a contract generating technology or technical information useful for the government in a way that is consistent with the foregoing model, discrimi-

nating variables that reflect commercialization activities are entered into the equation in a multiplicative (interaction) form.

Two sets of equations are tested. The first is a structural direct government benefit equation in which the incidence of commercialization (DCA) is multiplied by the congestion variable, (NOIDLE), and a negative coefficient is expected for this variable.

In the second set, reduced form government benefit equations are estimated. For these equations, a set of variables deemed to influence commercialization is substituted for the commercial spinoff variable, DCA. Other factors which influence the likelihood of an R&D contract achieving government objectives apart from commercial variables are discussed below.

(1) Mix of Government and Commercial Work (RCONT)

Firms who are active participants in government R&D business are likely to have a better idea of what the government needs than firms who are not doing as much work for the government. Contractors who perform a substantial amount of their R&D business with the government are more likely to have a greater appreciation of the government's scientific intentions and a better understanding of how to manage research programs under contract. A closer buyer-seller coordination because of extensive R&D contracting permits these firms to reduce the possibility of faulty delivery of government's scientific needs.

In addition, to the extent that self-financed R&D indicates commercial rather than government orientation in an R&D operations, it is possible to postulate that firms who do most of their work for the government do not try to seek out commercial opportunities as often as firms for whom a large

share of their total R&D is self-financed. Therefore, for the firm, the higher the proportion of government financed R&D, the higher the likelihood of government benefits, other things being constant.

(2) Type of Contractor (MANF)

If little weight is assigned to future benefits from superior government contract performance, contractors will find it worthwhile to divert their best technical resources from government oriented R&D to more commercially oriented R&D, and to take other actions which would enhance their future competitive prospects while detracting from current contract execution. Are manufacturing firms more likely to assign greater weights to future government contracts than service firms? Alternatively would it be more costly for manufacturing firms to default on an R&D contract?

If there is a possibility of a follow-on contract it can be argued that the value of such a contract is higher for firms with manufacturing capability. Service firms must incur additional costs such as licensing costs in arranging for the production of government needed technology. The value of the follow-on contract is directly reduced by the amount of licensing and related costs. Thus, all other variables held constant, government benefits are likely to be realized more often with manufacturing firms than with service firms.

However, it can also be argued that manufacturing firms have more to gain from commercial spinoffs than service firms, since firms with production capability do not have to incur additional licensing costs in the commercial exploitation of peripheral R&D outcomes. For this reason, manufacturing firms are more likely to divert their R&D resources to the explora-

tion of commercial possibilities, and therefore, the likelihood of generating products or processes that are usable by the government will be smaller.

To capture this second effect, the variable MANF is multiplied by the resource congestion variable, NOIDLE, and the interaction term is then included as an additional explanatory variable in the reduced form direct government benefits equation. A negative influence is expected for this interaction variable.

(3) Field of Technology (RM2 and RM3)

Two binary variables are included in the regression model to capture the differences in the underlying research potential across different modes of transportation. Presumably there are different probabilities of developing usable research results depending on the research base and position in the basic research and development spectrum. Systematic differences in the difficulty of research work and the opportunity for generating new products or processes that are usable by the government agency is partially captured by the mode dummy variables.

(4) Years Since Contract Completion (CLAG)

There are several reasons why the probability of a contract achieving government objectives may be influenced by the vintage of the R&D contract. Over time, R&D project officers gain contracting experience which permits them to be more effective in managing R&D processes and in dealing with private contractors. Procurement officers can perhaps more efficiently and precisely specify the ultimate R&D objectives and methods by which R&D

tasks are to be performed. If this is the case, then one would expect the incidence of government benefits to be higher for more recent R&D contracts than for contracts of earlier vintage. It could, however, be argued that with older R&D contracts there is more time for the government to have made use of the R&D results. Therefore a positive association between the likelihood of government benefits and time lag since contract completion would be expected.

(5) Size of R&D Contract (CONTC)

Are there systematic differences between large and small contracts in the generation of government benefits? It is argued here that smaller R&D contracts are more likely to be in support of specific operational functions, requiring well defined and relatively well known technologies. Scientific work on small R&D contracts is likely to be in the form of incremental improvement or adaptation of a state of the art technology for a specific purpose related to the missions of the department. Large value contracts on the other hand, are likely to involve long-term R&D objectives, often requiring comprehensive or radical improvements on advanced technologies. These longer term R&D goals are more basic in nature and have a greater degree of uncertainty. The government is less likely to be able to employ such a technology in a particular task when precise attributes and capability of the technology to be developed are relatively unclear.

To the extent that smaller contracts are generally employed for well defined government technologies with more specific uses, than long term basic research with vague objectives, a negative partial correlation is expected between the probability of government benefits and the size of the R&D contract.

(6) Experience and Scientific Capability of the Contractor
(AGEC and FP)

There is a large degree of uncertainty in any research and development process. The success or failure of an R&D project, or whether an R&D contract will result in usable technology depends in part on the efficiency of a person or organization to plan and manage research in the field in question. Success or failure depends on the ability of the R&D establishment to solve various unforeseen technical difficulties and problems. It depends on the ability to anticipate technical shortcomings and seek out alternatives before costly failures are encountered. To some extent these scientific capabilities come with experience.

To reflect the respective effects of experience and general ability to effectively perform research and development, the age of the firm and a measure of past successes are employed. To the extent that experience and the number of years the firm has been in business at the time of the contract are positively correlated, the incidence of a contract successfully achieving government objectives is hypothesized to be positively associated with age. Evidence of past successes would be provided by the average number of patents granted to the contractor. This past success variable provides an indication of the competence of the researchers or the ability to actually invent something. This variable is expected to exert a positive influence on the incidence of government benefits.

Furthermore, while the past success variable as defined, represents the ability to do research, it also represents the ability to transform research results into some commercially useful form. Since some firms have ways of commercializing and others don't, it is postulated here that when

there is congestion, the contracting firm with commercializing ability is more likely to sacrifice government benefits for a higher probability of commercial benefits than a contractor who lacks commercializing ability. Therefore, the past success indicator is introduced both in the additive and multiplicative interaction forms, where a positive and a negative influence are anticipated respectively,

(7) Size of the Contractor (REV) and Foreign ownership (FOR)

It has been argued that size may affect R&D performance by influencing the firm's prospect for appropriating returns from its innovative efforts. Furthermore, firm size may be related to diversification, and hence a larger firm may provide a broader range of uses for the uncertain outcome of an R&D project than a small single product firm. Therefore, one would expect larger firms to possess greater incentives for turning R&D opportunities into commercial advantages. The interaction between total revenue (a proxy for firm size) and the incidence of congestion is expected to exert a negative influence on the probability of government benefits.

It would be reasonable to expect foreign owned firms to be more concerned with commercial rather than government benefits as they are generally more diversified internationally and may be locally, and can commercialize a greater proportion of their research results. The foreign ownership variable is also interacted with R&D resource congestion variable, and a negative coefficient is predicted.

The model to be estimated can be summarized by the following general functional-form equations, where the i subscript denotes each individual contract, and the j subscript denotes each individual contractor.

Structural Equation

$$P(DG)_{ij} = f(RCONT_{ij}, MANF_j, AGE_{ij}, FP_j, RM2_{ij}, RM3_{ij}, CONTC_{ij}, \\ CLAG_{ij}, (DCA*NOIDLE)_{ij})$$

Reduced Form Equation

$$P(DG)_{ij} = f(RCONT_{ij}, MANF_j, AGE_{ij}, FP_j, RM2_{ij}, RM3_{ij}, CONTC_{ij}, \\ CLAG_{ij}, (RY*NOIDLE)_{ij}, (FP*NOIDLE)_{ij}, (REV*NOIDLE)_{ij}, \\ (FOR*NOIDLE)_{ij})$$

where $P(DG)_{ij}$ = Probability of an R&D contract realizing government benefits - i.e. benefits beyond what is contractually required.

$RCONT_{ij}$ = proportion of the j^{th} firm's R&D business with the government to the firm's total R&D in the i^{th} contracting year.

$MANF_j$ = 1 if the j^{th} firm is a manufacturing firm.
= 0 if the j^{th} firm is a service firm.

AGE_{ij} = age of the j^{th} firm in the i^{th} contracting year.

FP_j = Average patent stock of the j^{th} contractor.

$RM2_{ij}$ = 1 if the i^{th} R&D contract to the j^{th} firm is in the Rail and Surface mode.

= 0 otherwise.

$RM3_{ij}$ = 1 if the i^{th} R&D contract to the j^{th} firm is in the Air mode.

= 0 otherwise.

$CONTC_{ij}$ = value of the i^{th} contract awarded to the j^{th} firm.

$NOIDLE_{ij} = (1-IDLE)_{ij}$

$IDLE_{ij}$ = 1 if the i^{th} R&D contract employs R&D personnel or facility which otherwise would have been idle.

= 0 otherwise.

$CLAG_{ij}$ = a continuous variable representing time lag measured as the number of years since project completion to the year in which the project is evaluated.

DCA_{ij} = 1 if the i^{th} contract awarded to the j^{th} firm realizes commercial benefits as defined earlier.

= 0 otherwise.

RY_{ij} = 1 if the i^{th} contract to the j^{th} firm vests property rights with the contractor

= 0 otherwise

REV_{ij} = total revenue of the j^{th} firm in the i^{th} contracting year.

FOR_j = 1 if the j^{th} firm is foreign owned.

= 0 otherwise

6.3 Empirical Results

Table 6.1 shows an estimated structural form regression equation of the probability of a contract generating direct government benefits. Ordinary Least Squares estimation method and White (1980) method for generating heteroskedastically consistent variances were employed.

As expected, the probability of a contract achieving government objectives is positively related to the proportion of contractor's total R&D financed by the government. This variable is significant at the 95 percent confidence level for a two tailed test. The implication is that

the government is more likely to get R&D results which can be directly applied to mission oriented tasks, other factors being constant, when the R&D contract is awarded to a contractor with a relatively large proportion of R&D business with the government.

The likelihood of a contract realizing government benefits is also greater when it is awarded to a manufacturing firm rather than a service firm. This variable received strong statistical support, being significant at the 99 percent confidence level for a two-tailed test.

Contrary to expectations, the age of the corporation is negatively related to the incidence of government benefits and is significant at the 90 percent confidence level.

Consistent with expectations, the estimated coefficients for the contract size and time lag variables are negative and significant at the 95 percent confidence level. The latter implies that more recent contracts realized direct government utilization more often than earlier contracts. Perhaps this reflects the increased ability of the project officers to more fully specify the ultimate R&D objectives, and the methods in which research tasks are to be carried out.

When the past success variable is examined, a surprisingly negative and highly significant average effect on the probability of a contract achieving government R&D goals is observed. Entered in an additive form, the variable is supposed to reflect the ability of the contractor to do research. However, as discussed earlier, this measurement is also a proxy for the orientation and ability of the contractor to turn research results into commercial advantages. Therefore, unseparated, the negative coefficient could be reflecting the overwhelmingly negative effect of the latter.

Table 6.1

Determinant of the Probability of Realizing
Direct Government Benefits
(Structural Equation)

Independent Variable	Estimated Coefficient	T-Statistic
C	0.35803	2.2082**
RCONT	0.51853	2.3897**
MANF	0.82437	8.3583**
AGEC	-0.47798E-02	-1.9648*
RM2	0.34071	2.3189**
RM3	0.35383	3.1831**
CONTC	-0.10007E-05	-3.5935**
CLAG	-0.080777E-01	-4.5095**
FP	-0.28657E-02	-3.1199**
DCA*(NOIDLE)	-0.21942	-2.6704**

McFadden's $R^2 = 0.89$

$F(9,30) = 12.6226$

** Significant at 0.05 for a two-tailed test.

* Significant at 0.10 for a two-tailed test.

When the two influences are separated, as is done in the reduced form equation presented below, a positive effect would be expected for the past success variable in additive form, and a negative effect would be expected in the interactive form (with the congestion variable).

The estimated coefficient of the direct commercial benefit variable is negative and statistically significant, supporting the hypothesis that there is a trade-off between government and commercial benefits when R&D resources are limited.

On the basis of the F-statistic, the linear probability model above performed quite well. Together as a group, these variables explain statistically the incidence of an R&D contract achieving government objectives. The regression as a whole is significant at the 95 percent confidence level.

Since commercial and government benefits are likely to be determined jointly, the model should be estimated using a system of equations. However, as the model is not identified, only reduced form equations are presented.

Table 6.2 to Table 6.4 show variants of estimated reduced form equations for the probability of a contract generating direct government benefits. A set of variables considered to be important discriminating factors for the likelihood of commercial spillovers is substituted for the actual incidence of commercial benefits, DCA. As before, these variables, namely size of the firm, ownership, past success and property rights are interacted with the congestion variable, NOIDLE.

In all equations, the proportion of the contractor's total R&D financed by the government (RCONT) and the variable representing the contractor's

line of business (MANF) are both positive and significantly related to the incidence of a contract generating a technology or information which can be directly utilized by the government.

Age of the corporation shows no statistically significant relationship with government benefits, while intermode differences are statistically significant. Other factors held constant, the likelihood of a contract generating a technology or technical information that is directly useful for the government is greatest on average for R&D contracts in Air transportation, and smallest for contracts in the Surface and Rail mode.

Consistent with earlier hypotheses, the smaller the contract and the more recent the contract, the greater the likelihood of the government realizing its objectives.

The average effect of a contractor's research ability is statistically insignificant. This seems to indicate that earlier estimates (Table 6.1) could not statistically disentangle the separate and opposing effects of the past success variable on the probability of a contract achieving government objectives. Furthermore, it seems to indicate that the negative effect of the commercialization ability substantially outweighs the general positive effect of the contractor's ability to do research.

Statistical results obtained are not sensitive to specification changes. They are generally robust with respect to the direction of influence, the magnitude and the statistical significance.

Turning next to the discussion of commercial variables. Interactive size of the firm, past success and property rights variables all possess negative coefficients, as expected. However, only firm size and ownership

Table 6.2

**Determinants of the Probability of Realizing
Direct Government Benefits
(Reduced Form Equation)**

Independent Variable	Estimated Coefficient	T-Statistic
C	0.13915	0.78050
RCONT	0.74883	3.0924**
MANF	0.72631	7.4992**
AGEC	-0.10132E-02	-0.27740
RM2	0.26361	1.8772*
RM3	0.47659	3.2267**
CONTC	-0.70664E-06	-2.5701**
CLAG	-0.7317E-01	-4.2418**
FP	-0.12903E-02	-0.57389
FOR*(NOIDLE)	0.40236	2.6137**
REV*(NOIDLE)	-0.11612E-03	-1.8592*
FP*(NOIDLE)	-0.64748E-02	-1.5330
RY*(NOIDLE)	-0.15392	-0.78217

McFadden's $R^2 = 0.81$

$F(12, 27) = 9.8207$

** Significant at 0.05 for a two-tailed test.

* Significant at 0.10 for a two-tailed test.

Table 6.3

**Determinants of the Probability of Realizing
Direct Government Benefits
(Reduced Form Equation)**

Independent Variable	Estimated Coefficient	T-Statistic
C	0.13511	0.75286
RCONT	0.74942	3.0597**
MANF	0.72013	7.5487**
AGEC	-0.20103E-02	-0.68558
RM2	0.27748	2.1066**
RM3	0.50490	4.1396**
CONTC	-0.66885E-06	-2.5608**
CLAG	-0.71868E-01	-4.2995**
FOR*(NOIDLE)	0.41519	2.8537**
REV*(NOIDLE)	-0.10458E-03	-1.7989*
FP*(NOIDLE)	-0.81906E-02	-3.7184**
RY*(NOIDLE)	-0.11105	-0.69086

McFadden's $R^2 = 0.82$
 $F(11,28) = 10.9911$

** Significant at 0.05 for a two-tailed test.

* Significant at 0.10 for a two-tailed test.

Table 6.4

Determinants of the Probability of Realizing
Direct Government Benefits
(Reduced Form Equation)

Independent Variable	Estimated Coefficient	T-Statistic
C	0.13411	0.74120
RCONT	0.74631	3.0662**
MANF	0.72481	7.2398**
AGEC	-0.20834E-02	-0.70615
RM2	0.28061	2.0008*
RM3	0.50440	4.1549**
CONTC	-0.66662E-06	-2.5464**
CLAG	-0.71361E-01	-4.1770**
MANF*(NOIDLE)	-0.11504E-01	-0.10061
FOR*(NOIDLE)	0.42233	2.4006**
REV*(NOIDLE)	-0.10394E-03	-1.8215*
FP*(NOIDLE)	-0.82638E-02	-3.5617**
RY*(NOIDLE)	-0.10256	-0.55554

McFadden's $R^2 = 0.82$

$F(12,27) = 9.7179$

- ** Significant at 0.05 for a two-tailed test.
- * Significant at 0.10 for a two-tailed test.

variables are significant statistically. Contrary to the expectation, the incidence of government benefits is more prevalent amongst foreign owned firms.

Table 6.3 shows regression results for an equation which excludes the average effect of past successes variable, FP. Exclusion of FP substantially improved the performance of the commercial variables. Specifically, the ability of a contractor to turn an invention into a commercially useful form shows a strong negative influence on the probability of government benefits, implying that with resource constraint, firms which have greater commercializing ability are more likely to sacrifice government benefits for more commercial spillovers. Empirical results remain essentially unchanged when the interacted manufacturing variable (MANF*NOIDLE) is included as an additional explanatory factor (Table 6.4).

6.4 Conclusion

The probability that a contract generates government benefits is greater when the contractor is a manufacturing firm with an R&D operation which is relatively more oriented to government research. The probability of a contract yielding government benefits is also negatively related to commercial spin-offs, other things being equal. The three surrogate measures of commercialization included in the reduced form equations receive significant statistical support. First, the size of the contracting firm (REV) has a negative and significant impact on the probability of an R&D contract achieving government's objectives. Second, the incidence of government benefits is greater where the contracting firm is foreign owned. Finally,

the likelihood of a contract yielding government benefits is lower when the contractor is a firm with a more commercially successful R&D operation (measured in terms of the average number of patents received for inventions developed by domestic scientists and engineers).

The general implication is that the government may be able to enhance the likelihood of a commercial spin-off by contracting out to firms with the ability to exploit commercially the fruits of government research. However, when the contractor has no excess capacity, this may be done at the cost of a reduced likelihood of meeting government research objectives.

Chapter 7

Summary and Conclusions

Canada tends to perform a greater proportion of government financed R&D within the government than do a number of similarly situated OECD countries. While it may appear that Canada may be foregoing benefits which can result from the private performance of publicly funded R&D, this is not necessarily the case. A universal contracting-out policy such as the make-or-buy directive is not necessarily conducive to more effective use of research resources.

Whether contracting-out is beneficial depends on: (a) the respective administrative costs of contracting-out and intramural research; (b) the difference in resource costs of conducting R&D intramurally and contracting-out; and (c) the net difference in spin-off benefits generated under contract as compared with those generated by internal research.

Ideally, the determination of whether a project should be contracted-out and, if so, to whom the contract should be awarded, a substantial amount of information which is currently unavailable would be required. At present, little is known about which factors might influence the benefits and costs of contracting-out. Information needed for a systematic analysis has not been collected in Canada or elsewhere.

This study attempts to further our understanding of the circumstances under which contracting-out is beneficial. A number of interesting questions related to the different terms in the net social benefit equation from contracting-out are addressed quantitatively for the first time. This

study focuses principally on the investigation of the circumstances in which contracting-out, rather than in-house performance, is likely to increase the effectiveness of a given R&D resource. The empirical work relies on a wealth of micro data collected directly from the R&D contractors and government R&D project officers. This unique data set permits an investigation of the factors likely to affect the efficiency of contracting-out.

The analysis begins in Chapter 2 with an examination of the contracting process. With respect to the type of contract employed, sample R&D contracts were awarded on the basis of sole source negotiation more often than competitive bidding. This may have been the result of inefficiencies associated with R&D contract competition. Cost reimbursable contracts with a maximum price, and cost sharing contracts with a maximum price tend to be predominant.

On the distribution of property rights, we find that in approximately two-thirds of the cases, rights were retained by the government, and in the remaining one-third, contractors were awarded the rights with the government as a non-exclusive licensee. Theoretically, when the government cedes patent rights to the contractor it should expect that there will be additional benefits to the contractor from commercialization, and could, in turn, expect other returns from the contractor. However, assigning rights to the contractor may make it more difficult for the government to turn to an alternative supplier in the case of contract difficulties or follow-up procurements. Furthermore, greater commercial benefits to the contractor may imply a lower likelihood of realizing government research objectives, as is examined in Chapter Six.

According to government officials, the average cost of administering extramural R&D contracts amounts to 7 percent of the value of the con-

tracts. However, a case study implies that the magnitude of the management cost required to administer an R&D contract can be considerably more.

R&D contracts are seldom terminated. Contract termination is costly if it is difficult for the government to turn to an alternative contractor. It is more difficult to recontract with another firm if knowledge and expertise have to be redeveloped and research reproduced. Since the government is always at least a non-exclusive licensee and always has a right to past research, it must be that research results cannot readily be transferred to a new contractor.

In sum, the chapter argues that contracting costs will be higher when the research cannot be clearly specified and is subjected to a high degree of uncertainty, and when the research involves specific and irreversible commitments.

It is not clear however, to what extent this higher contracting cost can be avoided if the R&D were produced internally. More evidence on the cost of monitoring and administering internal R&D and on the circumstances under which such costs might be higher is clearly required. Further insights might be provided by asking government officials to indicate whether the research could have been done in-house and, if so, what the administrative problems would have been.

Chapter 3 examines the nature of R&D resources (idle or otherwise) absorbed by government R&D contracts, and investigates empirically the circumstances under which the resource cost of contracting-out is lower. Very little information on the opportunity cost of the resources used under contract is presently available. The little that is known, is generally inferred indirectly from related studies involving the effects of government-financed R&D on private R&D expenditures. While the literature devotes

considerable attention to the possibility that government-financed R&D may crowd-out self-financed R&D, only a few studies have investigated the means by which crowding-out might take place. This chapter developed a theoretical model of the relationship between contract and privately-financed R&D in the presence of congestion costs and commercial spillovers. The conditions necessary for crowding-out to occur were derived in this context.

The chapter then investigates the circumstances under which a contract employs resources that would otherwise have been idle. The evidence indicates that the opportunity cost of resources employed under contract is lower, other things being equal, when the contractor is a newer, less R&D intensive firm, with a relatively specialized R&D operation.

Of course, contracting-out itself may not imply increased effectiveness of R&D resource utilization. Again, it would depend on the relative costs of extramural and in-house R&D. Future surveys might usefully ask whether contract work could have been performed in-house and, if so, whether other in-house R&D would have been crowded out as a consequence. Ideally, crowding-out would be measured as a proportion ranging from zero to one for both intramural (government) and contract R&D. It could then be determined whether in aggregate contracting-out increases or decreases the extent of crowding-out.

The focus of Chapter 4 is R&D contract spillovers. It investigates the circumstances under which contract R&D results are more likely to be exploited commercially. The probability of a direct commercial spin-off is assumed to be a function of the characteristics of the contractor, the characteristics of the R&D, and the characteristics of the contract itself. A linear probability model which corrects for heteroskedastic errors and a logit probability model are employed. The results indicate that the like-

lihood of a spin-off is greater, other things being equal, when the contractor is a new, more commercially oriented firm, with a relatively more successful R&D operation and when the contractor is a large domestically owned firm.

Regression equations also showed that the likelihood of a contract generating commercial spillovers is greater when the contractor has the right to exploit technologies developed under contract. This however, should be interpreted cautiously. When a firm's proprietary knowledge or trade secrets are required for research purposes, the government often allows the contractor to retain property rights to contract technologies. As a consequence, the greater incidence of commercialization may be a consequence of the contractor's proprietary knowledge and expertise.

The results also indicate that the incidence of a commercial spin-off is greater, other things being equal, where the resource cost of contracting-out is higher (i.e. where resources absorbed by the contract would not have been idle). This, in turn, raises the possibility of a trade-off between greater commercial spin-offs and lower R&D costs.

Chapter Five further examines the relationship between of commercial spin-offs and the disposition of commercial rights. The possibility that the disposition of property rights is endogenous and is a function contractor and project characteristics is explored.

Wu's (1973) specification test indicates that the simultaneous equations estimation is appropriate. Because of the dichotomous nature of the endogenous variables, Heckman - MaCurdy's (1985) Simultaneous Linear Probability estimation technique and, Maddala and Lee's (1976) and Lee's (1981) Simultaneous Logit Estimation technique are employed. The results obtained are consistent with those discovered in Chapter Four.

Estimates of the property rights equation imply that a newer and a relatively smaller firm is more likely to acquire rights to technology developed under contract. As anticipated, when commercial spin-offs are expected from the research itself, the likelihood of a contract vesting property rights with the contractor, is greater.

The empirical analyses carried out in Chapters Four and Five are based on a zero-or-one type spin-off measure. Ideally, spin-off benefits would be measured as a discounted value of direct profits from the commercial applications of the technology, as well as a discounted value of indirect benefits (more incremental revenues from the employment of idle resources, knowledge acquired by scientists through the performance of contract R&D, and improvements in the productivity of firm's R&D operation). A future survey might usefully determine the magnitude of additional discounted profits. The effect of various contractual terms on the profitability of the contractor will be of particular interest to the government, one of whose objectives may be to minimize government research costs.

Chapter Six examines the factors that are likely to influence the probability of a contract generating R&D results which can be directly utilized by the government. The chapter develops a theoretical model which is used to assess the relationship between commercial spin-offs and government benefits, in the absence of excess capacity. The conditions for a trade-off between commercial and government benefits are then presented.

The empirical results indicate that the probability of a contract generating government benefits is greater when the contractor is a manufacturing firm, with an R&D operation which is relatively more oriented to government research. As anticipated, the probability of a contract yielding government benefits is negatively related to commercial spin-offs when

the contractor has no idle capacity. The implication of this finding is that the government can increase the likelihood of a spin-off by restructuring the terms of the contract or by selecting an appropriate contractor, however, this may be done at the cost of a reduced likelihood of meeting government research objectives.

Policy Issues

The Make-or-Buy Policy is potentially an effective means by which the government can stimulate innovation. Contracting-out government research to private companies implies a rearrangement of incentives and resource use. It has been argued that the likelihood of realizing commercial spin-offs is greater if government research is performed by a profit-seeking company than by a government organization. The argument is grounded in the belief that contractors can profit from the commercial exploitation of government research results whereas government researchers cannot. The ability to profit from government-funded technologies in turn, is determined by ownership structures or property rights arrangements. The empirical evidence shows that there is a definite link between commercial spin-offs and contractor's ownership of patent rights to technologies developed under contract. The implication is that property rights should be assigned the contractor if policy makers are interested in generating spin-offs. However, the analysis has also demonstrated that more commercial spin-offs may imply a lower probability of achieving government research objectives and higher R&D resource costs.

Whether selective contracting-out to increase the likelihood of commercial applications is beneficial on balance depends on the values attached to the spin-offs, the value of foregone government benefits, and

the higher resource cost of doing R&D. It may be useful for policy analysts to explore different mechanisms of granting property rights and other contractual designs to increase the efficiency of producing commercial benefits.

Evidence gathered concerning R&D benefits and costs associated with the contracting-out alternative is too limited and fragmentary at this time to offer a clear cut answer to the ultimate policy question of whether R&D contracting-out should be further encouraged.

Many extensions to this study are possible. These include estimating the costs of administering and producing in-house research, and the value of commercial spin-offs. Quantitative information on how the assignment of patent rights, along with other contractual terms, affect the profitability of a contractor might also serve to indicate the subsidy component in the R&D contracts. This may be of significant interest to policy makers who are concerned with government support of industrial R&D.

It is also natural to examine other policy questions such as: how does R&D contracting-out affect entry and exit conditions, and industry concentration ratios?; and, can the contracting-out policy be used to redistribute R&D activities and to promote a more regionally intensive use of skilled scientific manpower?

This study has initiated the process of filling in some of the gaps in the R&D contracting-out literature. Admittedly, it has addressed only a subset of the issues. Nonetheless this study represents one of the few quantitative investigations into the R&D contracting-out process. It is able to provide new insights into the circumstances under which contracting-out is likely to be beneficial. In the process the study has raised more questions that must be answered before one can conclusively pronounce on whether or not the Make-or-Buy policy should be encouraged.

Appendix A - Contractor Questionnaire
INDUSTRIAL BENEFITS OF TRANSPORT CANADA

R&D CONTRACTS

QUESTIONNAIRE

Information about your company

Please indicate your principal line of business:

- ☐ Manufacturing
- ☐ Engineering Consultants
- ☐ R&D Consultants
- ☐ Transportation and Communications
- ☐ Mining
- ☐ Other - please specify: _____

Age of your company (year of incorporation): _____

Approximate size of your company in 1978:

Sales _____

Employees _____

R&D activities of your company:

Self-financed R&D in 1978: _____

Self-financed R&D as a proportion of total R&D undertaken by your company in 1978: _____

Information about Contract No. 1ST78-00069

Title: Evaluation of Truck Tire Rolling Resistance, Bearing Losses and Road Surface Effects on Rolling Resistance (Aug. 78 - Jan. 82).

Has the ☐ technology or ☐ information developed under the contract been utilized?

☐ Yes

☐ No

If yes, please indicate how this technology or information has been utilized?

☐ Direct commercial applications

☐ by your company

☐ by other companies

☐ Technology used by the government

☐ Used as a base for follow on research

☐ on behalf of the government

☐ for your own purposes

Please indicate whether the research conducted under this contract had any of the following incidental (by-product) results.

☐ It contributed to the successful completion of other R&D projects being conducted by your firm.

☐ It allowed you to utilize R&D facilities which would otherwise have been idle.

☐ It allowed you to utilize R&D personnel who would otherwise have been idle.

☐ It enabled you to improve your company's existing product line.

☐ It allowed your personnel to learn a new technology which will enable you to enter a new line of business.

Appendix B - Project Officer Questionnaire

1. To the best of your knowledge, did this project have any direct commercial pay-off?

☐ Yes

☐ No

If yes, please indicate the nature of this pay-off:

a) New Product	☐ Used by the federal government
	☐ Sold elsewhere
b) New Process	☐ Used by the federal government
	☐ Licensed elsewhere
c) Technical Information	☐ Used by the federal government
	☐ Licensed elsewhere

2. To the best of your knowledge, did this project involve any of the following forms of indirect pay-off?

- ☐ (a) Contribution to successful completion of later projects.

If so, did the later projects have a direct commercial pay-off as defined in (1)?

Please specify: _____

- ☐ (b) Allowed the contractor to keep the research team together when it might have otherwise have been dispersed to non-R&D activities or laid off.

- ☐ (c) Allowed contractor to acquire new technical skills which have subsequently been used to:

☐ (i) develop new products or processes with a commercial pay-off.

☐ (ii) engaged in more advanced R&D work on behalf of:
☐ the federal government.
☐ other parties.

☐ (iii) other.

- ☐ (d) Assist the contractor in discerning new opportunities for the exploitation of the technological information at its disposal.

- ☐ (e) Allowed the contractor to acquire or maintain specialized research facilities which could not otherwise exist in Canada.

3. To the best of your knowledge, did this project produce any incidental technology?

☐ Yes ☐ No

If yes, please indicate the nature of this by-product:

- ☐ (a) New product or production process
☐ (b) Improved products or production processes
☐ (c) Other.

4. In your opinion, did the contractors' own R&D spending (exclusive of the amount received under the contract):

- ☐ (a) increase
☐ (b) decrease
☐ (c) remain unchanged

as a consequence of the receipt of the contract? (If increases occurred after the period covered by the contract, please indicate.)

5. In your opinion, does the general clause DSS 1036 inhibit contractors from seeking commercial application of technologies developed under contract?

☐ Yes ☐ No

Appendix C

Contracts Examined (by Name of Contractor)

1. TDC Contracts

Arctec Canada

Installation of Instruments for Ice-induced Vibration measurement aboard USCGC polar Sea Development of model for Ice Breaking (IST80-0073)

Ice Class Propellers and shafts - Model Test (IST80-00143)

Bayle Engineering Ltd.

To Develop and Test a Prototype Quasi-Doppler Marine UHF Direction Finder (OST81-00101)

Doppler Radio Direction Finder (09SD.T8200-9-9530)

Bombardier

Etudier Conceptuelle D'un Systeme de Transport Urban a Capacite Intermediare (OST5-0088)

Canadair

Advanced Designs for Fuel Efficient Small Transport Aircraft - Phase I (107903)

Establishment of design data leading to the development of more fuel efficient small transport aircraft (Phase II) (OSD80-00004)

Establishment of design data leading to the developing of more fuel efficient small transport aircraft (Part I of Phase III) (OSD81-00018)

Advanced Design Study of Future aircraft concepts (OSD82-00106)

Canadian Pacific Ltd.

Rail Metallurgy Development (OST5-0065)

Canadian Pacific Consulting Services

Development of a Computer-Aided Train Dispatch System using 8 Colour Display (OST76-00115)

Evaluation of Urban Rail Facilities for Public Transit Applications (OST5-0071)

Canac Consultant Ltd.

Canadian Controlled Climate Test Centre, Feasibility Study (OSD79-00111)

Acres Consulting Services Ltd.	Railway Test Track facility, A Concept Definition Study for Can. Guided Ground Transportation (OST5-0079)
Chrysler Canada Ltd.	Evaluation of Propane-Fueled Vehicle Designed for On-Line Production (IST80-00186)
	Optimization of Propane Engines for Light Duty Vehicles (ISD81-00180)
Cominco	Research and Development Related to the Negative Current Collector of Zinc-Alkaline Batteries (IST81-00037)
	Zinc-Alkali Battery Research for Cold Weather Engine Starting (OSD83-00110)
Davis Engineering	Protection of Propeller in Ice (OST79-00047)
	Truck Tire Rolling Resistance, Bearing Losses and Road Surface Effects on Rolling Resistance (IST78-00069)
De Havilland	Air Cushion Ice Breaking Bow Development Comprehensive Theoretical & Lab. Analysis of ACIB (OST81-00158)
	Development of Technological improvement leading to the design of more efficient STOL Transport Aircraft (107902)
	Development of Technological Improvement leading to the Design of More Efficient STOL Transport Aircraft (OSD80-00036)
DSMA	Controlled Climate Test Facility Study (OSD81-00023)
	Collaboration and Support to the St. Lawrence Seaway Authority in Testing Electric Vehicles (IST78-00203)
	Evaluation and Development of Electric Vehicles - Phase I (IST79-00049)
	Evaluation and Development of Electric Vehicles - Phase II (ISU80-00058)
Glenayre Electronics Ltd.	Development of Locomotive Identification and Control Techniques for Railway Signalling Applications (Development Phase) (OST5-0005)

	Development of Locomotive Identification and Control Techniques for Railways Signalling Applications (Phase II) (OST77-00006)
	Train Location Identification and Control System (LICS) Prototype Equipment Construction (OST78-00151)
German & Milne	Adaptation and Installation of NAWS Strain Gauging on the CCG Ship Pierre Radisson (OSD82-00161)
	Hull Stress Warning System (IST81-00021)
MPB Tech. Inc.	High Intensity Plasma Light Source for Marine Transportation (OST76-00099)
	Development of a remote Sea-Ice Thickness Sensor, Phase I, Stage 2 (OSD78-00033)
	Development of an antenna suitable for a remote sea-ice thickness sensor (OSD80-00051)
	Field trials of the TDC/MPBT Advanced Prototype Sea-Ice Thickness Sensor (OSD82-00167)
Pratt-Whitney Aircraft	Development of Technological Improvement in Gas Generator Turbines leading to the design of more Energy Efficient Small Turboprop and Turbofan Engine (Phase II) (OSD79-00109)
	Development of Technological improvements in gas generator turbines leading to the design of more energy efficient small turboprop and turbofan (OSD80-00009)
	Experimental and Analytical research on a mixed flow turbine (OSD81-00080)
	Gas Turbine Ceramics Technology (OSD82-00127)
	High Efficiency Combined Cycle Gas Turbine Plant for Marine Propulsion (OST76-00064)
Satel	Unattended Navigation and Communications Facility (UNAVCOM) (OST78-00147)
Textron Canada: Bell Aerospace	Interim Notch Seal for HSL-533 Air Cushion Ice Breaking Bow (OST81-00158)

2. Transport Canada Contracts

Goodwood Data Systems Ltd. To provide displays of Radar/satellite weather information on ATC radar systems (IST80-00041)

Digital Methods Ltd. ATC Data Link Study and Simulation (IST80-00038)

Development of a computer-based system to manage a tactical and strategic air traffic flow control system - Phase I (IST80-00007)

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