APPROPRIABILITY AND PUBLIC SUPPORT OF R&D IN CANADA*

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This paper investigates the extent to which considerations of inappropriability, a form of market failure, guide federal support to private industrial R&D in Canada. Statistics of the overall allocation of subsidies between grants and tax credits show little evidence at an inappropriability rationale. Econometric analysis of grant distributions, using a recently proposed operational concept of inappropriability, supports this conclusion at an aggregate level, but gives different results when a particular grant program is probed.

Keywords: Industrial research and development, inappropriability, grants, tax incentives.

INTRODUCTION

The remedy of market failures is possibly the most popular justification of public intervention in the economy. The objective of this paper is to analyze the extent to which the Canadian federal government appears to heed market failure rationales in the way it supports R&D. We aim to understand the intent of the Canadian federal government's support of research and development in the private sector. From a normative viewpoint such a support should correct some form of market failure. The most common of these is ascribed to the situation in which social returns from R&D-generated innovations exceed private returns and the private entrepreneur, due to this gap designated as *inappropriable*, will invest less in R&D than is socially desirable. Other aspects frequently mentioned with respect to innovative activity include high, uninsurable risk and a large minimum efficient scale to carry out industrial research — both also resulting in underinvestment in innovation.

In the next section we give first some statistics to show the extent of Canadian federal taxpayer support for public and private R&D. Then we indicate what the allocation is of federal funds for private industrial R&D as between grants and tax credits. We reason that this allocation shows few signs of taking inappropprability into account. In the following

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section we review briefly the literature on spillovers that indicate the presence of inappropriability. We then invoke an operationsl concept of inappropriability and test the hypothesis that it is a determinant of R&D grants. For this analysis we use data on grants and contracts to SIC industries, and on grants under a specific federal program to individual firms aggregated to the SIC level.

The results are contradictory: on the aggregate level (between total grants and tax credits, and when total grants and contracts are related to SIC industries) there seems to be no connection between inappropriability and subsidy; while there is some evidence of it under one specific grant program.

FEDERAL EXPENDITURES ON R&D — AN AGGREGATE VIEW OF ITS ALLOCATION

In this section we first take a look at the sheer size of the Government of Canada's expenditures on research and development in the natural and engineering sciences and make some comparisons of it to other OECD-member countries. We then raise the question as to whether the distribution of federal R&D funds in the natural sciences and engineering is fashioned in a manner that would support innovation — encouraging activities where they may fall short of what is often termed socially desirable levels.

In 1984 one of the present writers stated that "The fact remains, however, that no comprehensive critical appraisal, based on numerical analysis, of Canada's central government's outlays on and benefits from technology exists".[1] This remains true today. However, such a task would exceed the scope of this inquiry. A brief exploration of the allocation of tax-supported R&D expenditures is possible by recourse to a by now well accepted normative framework, first proposed by Noll[2] and elaborated since, for instance, by Tarasofsky[3] and Grossman.[4] This framework goes beyond the issue of appropriability which, nevertheless, remains central.

The failure of private markets is the principal reason given for taxpayer subsidisation of private sector R&D. The first source of market failure is the discrepancy between total (social) net benefits of an innovation and the benefits accruing to the private innovator. The determinants of this discrepancy — of this in appropriability — are discussed further on in this paper. The second source of market failure is the supposedly extraordinary, and so uninsurable, risk accompanying technological innovation. The third source, presumably with roots in the imperfection of capital markets, is the putative considerable minimum efficient size for R&D activities, making it impossible for small enterprises to afford engaging in them. Noll, who ably summarises these presumed sources of market failure, argues that it is not evident at all from empirical research that such sources of market failure are strongly present.[5]

Nevertheless these three, along with the acknowledged need of governments to keep abreast of technology for a better delivery of its services, are the elements most often advanced for taxpayer support of technological change. It should be also pointed out that financing research aimed at the general advance of science and technology, such as carried out in universities, is usually classed under the inappropriability heading: the private sector will probably invest less than is desirable in basic research.[6] Finally, the market failure framework can also be stretched to accommodate the diffusion rather than the generation of innovations. Some government support is always given to firms to provide information which would facilitate the adoption of technological advances.

Let us now take a look at R&D monies in the April 1 to March 30, 1991-1992 federal budget in the natural sciences and engineering areas. Note that of the total $3,287 million, $729 million or 22 per cent was destined to industry, of which $321 million or 44 per cent went to industry in the form of grants and contributions.

TABLE 1
ESTIMATED FEDERAL R&D EXPENDITURES, BY PERFORMER AND ACTIVITY, 1991-92

	Performer					
Activity	*Intramural*	*Industry*	*University*	*Foreign*	*Other*	*Total*
	($ millions)					
In-house R&D	1124	—	—	—	—	1,124
R&D Contracts	46	406	47	12	24	535
R&D Grants and Contributions	—	321	709	113	75	1,219
Research Fellowships	22	3	46	16	0	89
Extramural R&D Administration	136	—	—	—	—	136
Captial — R&D	187	—	—	—	—	187
TOTAL	1515	729	802	141	100	3,287

Source: Industry, Science and Technology Canada, *Selected S&T Statistics 1991*, Ottawa, December 1991.

An international comparison, in Table 2, indicates that around 1989 the Canadian federal taxpayer shouldered about 44 per cent of the national R&D outlays, roughly equal to the proportional burden carried by French and US taxpayers. When government civil R&D appropriations are expressed as a percentage of the gross domestic product, Canada ranks higher in 1989 than the United States or Japan.

Canadian taxpayer support of R&D cannot therefore be regarded as ungenerous. Naturally, the above statistics do not take account of the tax stimulants to R&D or, if you prefer, of the tax revenue foregone. Canadian tax concessions for industrial R&D are the most generous — or among the most generous depending on the province — in ten OECD countries, as Table 3 indicates. This is due, in substantial measure, to the system of federal investment tax credits available to R&D performers.

TABLE 2
SELECTED INTERNATIONAL COMPARISONS OF GERD, 1989

Country	*GERD*	*GERD/GCP*	*Share Financed by Public Sector*
	(US$ bil.)	*(%)*	*(%)*
Japan	58.0	3.04	19.9
FRG	26.7	2.88	33.9
U.S.A.	130.3	2.83	48.2
U.K.[a]	17.0	2.20	36.5
France	19.0	2.32	49.9
Canada	6.7	1.33	44.0
Australia[a]	2.9	1.24	54.6

[a] 1988.
Source: OECD, *Main Science and Technology Indicators,* 1991, No. 1.

TABLE 3
COMPARISON OF B-INDEXES IN 10 COUNTRIES, 1989

	1989	
Country	*B-index*	*Rank*
Canada	.657	1
United States	.972	5
Australia	.703	2
Japan	1.003	7
Korea	.805	3
France	.813	4
F.R.G.	1.027	8
Italy	1.033	9
Sweden	1.040	10
United Kingdom	1.000	6

Note: This comparison assumed for Canada a Quebec-based corporate income tax system; for the U.S., the California tax system; for Korea, the claiming of double depreciation incentive; and for France, the claiming of the volume-based investment tax credit.

The B-index is defined as the after-tax cost of $1 of R&D expenditure, divided by one minus the tax rate, or ATC/(1 — tax rate). The lower it is, the more hospitable the tax climate is to R&D outlays.

Source: Jacek Warda, *International Competitiveness of Canada R&D Incentives: An Update,* Report 55-90, Ottawa: The Conference Board of Canada, June 1990.

The conclusion is warranted then that Canada's central government and its federal taxpayers incur a substantial expense in financing research and development activities, whether carried out *intra muros*, in universities, or in industry. This conclusion holds whether we look at the absolute amounts or at international comparisons.

How is funding to industrial research allocated? Public support to private-sector R&D can be of the indirect as well as of the direct kind. Indirect support can be viewed as a consequence of measures designed to stimulate activities with which research may be associated: investment tax incentives, grants to environmental protection projects, etc.[7]

Direct support itself is of two sorts: tax incentives and subsidies. The essence of tax abatements as stimuli to research activity is that they can be made available, on uniform terms, to all R&D performing firms. In

Canada, current and capital R&D expenditures are both fully deductible as well as qualifying, under generous conditions, for tax credits. All incorporated business can take advantage of the R&D provisions of the income tax act, with certain geographic areas and with smaller businesses getting more generous treatment. Subsidies or grants to industrial R&D must, however, be applied for on an individual project basis and are submitted to an often lengthy bureaucratic process which ensures conformity with the granting program's conditions.

The respective organisational, economic and political advantages or drawbacks of the two direct ways of supporting private-sector research are well known and have been discussed at length elsewhere.[8] For our purposes it is important to underline just one of the differences between them. The uniform, standardised requirements of reporting under the income tax act are ill-suited to discriminate against firms which would have undertaken R&D *without* the tax incentive in any case. Grant conditions, on the other hand, can be designed to make sure that the project satisfies the triple requirements of firm, industry and economy-wide incrementality: the project will cost more than the present value of its expected private benefit; there is no other firm that could have undertaken it without subsidy; the economy-wide benefits must be sufficient to offset the subsidy granted and the cost of its delivery.[9] The satisfaction of even these conditions, as we shall see, does not however guarantee social optimality.

While in principle tax provisions could be made as complex as granting criteria, in practice tax administrations are reluctant to equip themselves with the advisory committee apparatus typically required to decide on the eligibility of projects for grants. It is therefore in the grant area, rather than in the tax incentive provisions, that one should look for signs that appropriability, or rather the lack thereof, should drive a wedge between the costs of an innovation project and its expected private benefits.

But let us pause and consider again the use of public funds to neutralise the occurrences of spilling, inappropriable innovation benefits. The avowed purpose is to counter the suboptimal R&D — innovation — expenditure of the enterprise which cannot totally enforce property rights to the knowledge it created. However, while the innovative activity of the originating firm may be depressed by lack of appropriability, it is not certain that the beneficiaries of knowledge spillovers will not increase their own R&D efforts to an extent that will neutralise the initial consequences of inappropriability.

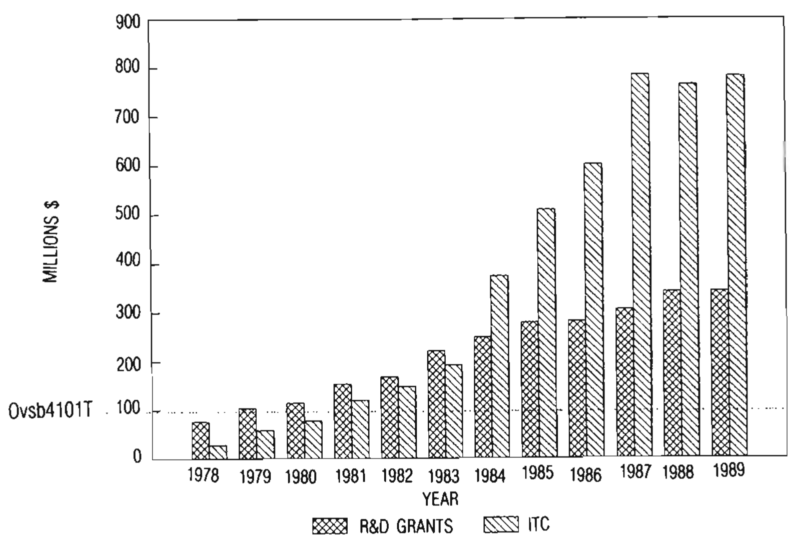
There is a growing awareness that for a business to absorb spilling technology from competitors or adjacent sectors, it must itself engage in substantial R&D activity. In an influential article, Cohen and Levinthal show that a firm's absorptive capacity is a positive function of its own R&D effort.[10] We could add to this the well known phenomenon of R&D rivalry, so prominent in certain industries.[11] It would therefore seem that simply to document the existence of inappropriability is not really a sufficient reason for R&D subsidisation.

The government subsidiser should therefore extend his enquiry into a subsidy application to cover the likelihood that spilling knowledge may engender innovative absorption. This is a tall order, possibly feasible under a grant system, but quite impossible in a subsidy system based on tax stimulants. It seems therefore that tax expenditures are an unlikely vehicle for remedies to inappropriability. It is consequently of interest to examine, for instance, the growth over time of tax expenditures for R&D and its relative magnitude compared to direct subsidies.

Graph 1 offers a global view of grants and tax expenditures on the Canadian federal scene over 12 years, starting in 1978. Graph 2 shows what proportions of private intramural R&D have been financed by grants and by investment tax credits.[12] The tax credit figures are substantially underestimated, since they do not contain claims under the notoriously abused scientific research tax credit (SRTC) scheme, available between 1983 and 1985 in addition to the regular investment tax credits for R&D.[13]

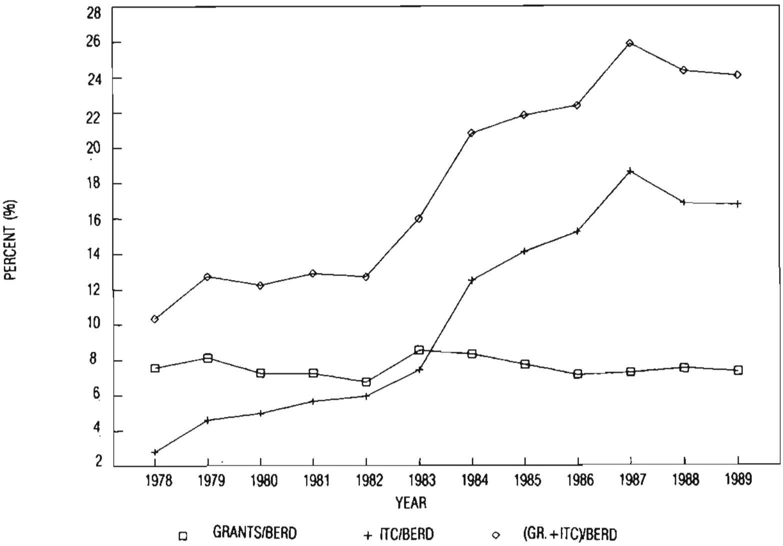
Revenue Canada, in a letter to the writers, estimated in March 1989 that the cumulative tax credits claimed under the SRTC label amounted to $3,564 billion from the start (1983) to the end (1985) of the program. It would seem, therefore, that at least for the 1983-4-5 period the tax claims listed in graphs 1 and 2 are too low by $3.5 billion.

GRAPH 1
FEDERAL GRANTS GIVEN AND INVESTMENT TAX CREDITS CLAIMED WITH RESPECT TO INDUSTRIAL R&D



Sources: For grants see Statistics Canada, *Federal Scientific Activities 1991-92,* Ottawa: 1991, Table 3.2 and previous yearly issues. For investment tax credits see Statistics Canada, *Science Statistics* (bulletin), April 1978 to 1984 inclusive; 1985-6-7 figures from letter of Revenue Canada official dated March 9, 1989; 1988 and 1989 figures from same source as for Table 1.

GRAPH 2
GRANTS AND INVESTMENT TAX CREDITS (ITC) AS PERCENTAGE OF BUSINESS ENTERPRISE INTRAMURAL R&D EXPENDITURES (BERD) IN CANADA, 1978-89



Source: BERD from Statistics Canada, *Industrial R&D Statistics 1989,* grants and tax credits from Graph 1 sources.

From Graph 2 it is readily apparent that the proportion of grants in the financing of BERD is at best holding steady at around 7 per cent. It is the investment tax credit which appears to grow rapidly, both in absolute and relative terms.

Two conclusions can be drawn from this swarm of numbers. The first is that private sector research relies considerably on outright subsidisation by means of tax credits and government grants. (International comparisons would show less generous tax treatment and a greater reliance on government research contracts elsewhere). Second and of more immediate import, the increasing preponderance of tax credits would seem to indicate a lesser reliance on inappropriability as a criterion in the allocation of public support.

This opinion could be contradicted by the argument that while tax credits are not responsive to the degree of inappropriability, they still reflect the government's concern that R&D is typically underfunded due to imperfect appropriability of returns to innovative efforts. But is there actually any evidence that the Canadian federal government has been preoccupied with inappropriability?

While the innermost thoughts of politicians and their public servants cannot be fathomed, it can be said that the "i" word is not to be found in official announcements. The great happening on the federal stage with respect to technological innovation occurred in 1986 with a federal-provincial gathering in Winnipeg. A year later this led to a joint federal-provincial declaration of a National Science and Technology Policy and, in rapid succession, to the federal InnovAction — the Canadian strategy for Science and Technology and, finally, to the federal Decision Framework for Science and Technology, in application since 1988. Despite the profusion of capitalised letters, none of the expensively printed and disseminated policy statements mentioned questions of appropriability, or indeed of market failure. Neither did the more operationally oriented yearly federal budget statements.[14]

Just about the only clutch of occasions on which the defense of intellectual property rights was invoked was when a government bill to strengthen patent rights in the pharmaceutical industry was fought over in parliament during 1986-87.[15] Patents rights, while improving appropriability, are not, however, grant or tax subsidies and the whole debate appeared uninformed by the Arrovian notion of knowledge as a public good. In short, the "i" word was not used in the government's argument.

Since in the next section we present an econometric test of the inappropriability—as—government-subsidy-rationale hypothesis, using data on grants, a few words are in order to describe the two main grant programs which were in effect during the period from which our data spring. As will be explained later, only one of them, the Industrial and Regional Development Program (IRDP), was subjected to individual analysis; the other was lumped together with IRDP for an aggregate probe.

The oldest industrial assistance program with a component of R&D support, the Defence Industry Productivity Program (DIPP), originated in 1959 and is administered by the variously called federal ministry of industry. Its purpose is "to develop and maintain strong defence-related industries across Canada that are capable of competing successfully over the long term in domestic and export markets."[16] It is the most important channel of federal government subsidy to private R&D as can be seen in Table 4. (Since DIPP is concentrated among too few industries, we could not analyse it with our methodology described in the next section.)

The second among the large industrial R&D subsidy schemes was until recently the Industrial and Regional Development Program (IRDP) with a large R&D component. It ended officially in June, 1988 and was succeeded by a host of more specialised programs. IRDP and its predecessors as well as its successors have been administered by Ottawa's ministry of industry which, too, sported a number of names, the current one being Industry, Science and Technology Canada. Subsidies awarded under this program and under EDP are listed in Table 5. In his appraisal of the Enterprise Development Program, the immediate precursor of IRDP, Tarasofsky stated that its most striking administrative shortcoming lay in the failure to recognise the relevance (and to provide for the projection) of the proposed projects' inappropriable benefits.[17]

TABLE 4
THE TWO MAJOR FEDERAL R&D/INNOVATION GRANT PROGRAMS, 1979 TO 1988
($000)

	EDP	*IRDP*	*DIPP*
79/80	30,400[a]		
80/81	47,000[a]		121,300[c]
81/82	69,400[a]		151,600[c]
82/83	65,800[a]		151,900[c]
83/84	70,144	16,836[b]	169,200[c]
84/85		46,887	130,700[c]
85/86		51,006	203,192[c]
86/87		55,871	109,303[c]
87/88		35,233	135,158[c]

[a] Budgeted
[b] Starts July 15/83
[c] Authorised

Sources: For EDP A. Tarasofsky, *The Subsidisation of Innovative Projects by the Government of Canada*, Ottawa: Economic Council of Canada, 1984; for IRDP and DIPP, Department of Regional Industrial Expansion annual reports and OECD, DSTI, *Financial Incentives for Innovation: Canada,* Paris, November 1984.

IRDP, introduced in July 1985, was in a sense the product of years of experimentation with other forms of industrial assistance programs. In a penetrating article devoted to its first year of operation, Atkinson and Powers point out that the predecessor Enterprise Development Program had already distinguished among grants for innovation, modernisation, marketing and restructuring.[18] While IRDP incorporated these program elements explicitly in the new subsidy scheme, it did not clearly establish any priority ranking among them. As a consequence, serious discrepancies were uncovered between announced criteria for awards and actual disbursements. In these authors' opinion, subsidy programs intended as adjuncts to competitive markets suffer from the absence of a clear economic rationale and tax the ingenuity of bureaucrats more than the average piece of state intervention.

Very briefly, IRDP provided assistance, in the form of grants or loans, to innovation feasibility studies, new-product and process research, industrial design and development of technological capability, and a host of other non-innovation related activities.[19] Up to 50 per cent of eligible costs were covered, depending on the regional location of the project. Conditions for assistance approval included: 1) Incrementality — the project would not proceed without government aid. 2) There is a significant technical risk, but there are good prospects for a commercial exploitaton. 3) Expected significant net economic or social benefits to Canada within reasonable bounds of risk.

This summary of assistance criteria does not begin to encompass the complexity of provisions which led to the developments described by

Atkinson and Powers. Advisory boards, established in accordance with the IRDP bill, presumably injected a flexibility into the application of the regulations which could have made the interpretation of the above three provisions more subjective.

CAUSES AND INCIDENCE OF INAPPROPRIABILITY

Imperfect appropriability of returns on R&D investment appears according to Griliches in two related, but distinct forms.[20] The first is an externality which exists when the price of an R&D intensive product or input is sold at less than its full quality price.[21] This productivity spillover results in a measurement problem related to R&D embodied in new products, inputs and capital goods. The second form of spillover is access to information obtained at less than full cost.

Productivity spillovers

Unless the price of a new consumer product is fully adusted for higher quality, the return on the embodied R&D investment is in part shifted from the innovating firm to the consumer. Although the positive externality accruing to the consumer is not statistically observed, the total or social benefit exceeds the private benefit.

The R&D embodied in inputs shifts part of the returns to R&D investment and the measurable productivity effect of R&D from the industry of origin i, to the industry of use j. Most econometric studies of the effect of R&D on productivity growth have found that the elasticity of productivity growth with respect to R&D embodied in purchased inputs (called alternatively indirect R&D, or used R&D) is generally superior, and often more statistically significant, than the elasticity to R&D in the industry of origin.[22]

Information spillovers

Aside from the market imperfections related to R&D embodied in new consumer goods and/or in interindustry flows of intermediary and capital goods, there are what Griliches calls, the "real" intra- and inter-industry "spillovers" of knowledge capital.[23] These are elements of information obtained at lower than full cost by a firm k, from other firms $m \neq k$ in the same industry i, i.e., the intra-industry spillover and from firms in other industries $j \neq i$, i.e., the inter-industry spillover.[24] This "borrowing" is not particularly related to the purchased input flows. The flow of unpaid knowledge between firms and industries is more likely to be based on the technological proximity of firms and industries than on the input-output structure.[25]

Various technology flow matrices were created as proxies for the technological proximity which is believed to be underlying the spillover flows. The technological proximity can be approximated from information available in: 1) an innovation matrix (a matrix $[I_{ij}]$, where the rows i, indicate the industries of origin of innovations I, and columns j, the industries of use) and/or 2) in patent data banks (a matrix of patents $[P_{ij}]$, classified by the industry of origin i, of the patenting firm and to the most likely industry of their use, j).[26] Using the Canadian PATDAT data bank, Seguin-Dulude, identified significant differences between industries that are a source of technology and those using mainly technology developed by the first group.[27]

The various studies mentioned used different data and methodologies for modelling interindustry flows of technology but, with the exception of Hartwick and Ewen,[28] they all show that there are significant inappropriated flows of technology between industries. They also share the common problem of confounding the effects of embodied R&D (input-output based technology matrices) with information spillovers (patent matrices). Instead of modelling the technological flows, Bernstein lets the data determine the effect of such flows by regression coefficients.[29] Thus while there is a growing number of studies that identify the existence of inappropriable spillovers of technology, there is not yet one generally accepted methodology for their measurement.

AN EXPLORATORY STATISTICAL ANALYSIS OF THE INDUSTRIAL DISTRIBUTION OF FEDERAL GRANTS

To our knowledge, no innovation (product or process) level evaluations of social benefits of industrial innovations were performed in Canada. A pioneering study of this kind in the United states by Mansfield demonstated that social benefits were significantly superior to private benefits.[30]

The relationship between productivity growth and subsidised R&D examined by Hanel suggests, however, that Canadian federal R&D grants were not distributed across industries in a manner that would increase their productivity.[31] Scherer and Terleckyj arrived at similar conclusions for the United States.[32]

In this section we undertake a statistical analysis of the industry-by-industry distribution of federal R&D grants in Canada. The objective of our statistical exercise is to explore the relationship of various proxies of market failure (appropriability, risk, indivisibility) to the distribution of grants among industries. The model will be tested on two levels. First, with respect to the total federal grants and contracts, second with respect to the IRDP grant program.

The model

R&D subsidies, or grants as they are called in Canada, are awarded to firms that made an applicaiton which, presumably, has demonstrated the feasibility of the project, the need of public support and the benefits to society.

Suppose that the federal government distributes the innovation related grants among industries so as to correct the principal sources of market failure likely to be associated with innovative activity. Then the share of grants received by an industry would be in inverse relationship to appropriability and proportional to high, uninsurable risk and a large minimum efficient scale of projects. Schematically, a pre-theoretical model for a statistical investigation of the relationship between the distribution of grants and different aspects of market failure can be specified as follows:

$$\text{Grant \%} = f(\underset{-}{\text{APPROPRIABILITY}}, \underset{+}{\text{RISK}}, \underset{+}{\text{SIZE}}, \text{OTHER VARIABLES})$$

Dependent variables

Federal grants and contracts

We first try to account for the distribution of total federal grants and contracts among industries.[33] The units of observation in our exploratory data analysis are the two and three digit SIC industries used in the statistics of Canadian R&D expenditures by industry.

Public support of defence-related R&D is mostly justified on public sector functions rather than on appropriability grounds. The dependent FED variable is therefore defined as the percentage of total federal grants and contracts net of Defence Industry Productivity (DIPP) grants, awarded in 1987.

IRDP grants

Next, the firm-level information on the amount of the innovation-related grant received, the grant-eligible cost and the industry of origin was aggregated so as to fit the industrial breakdown used in R&D statistics by Statistics Canada.[34] The dependent variable, IRDP, is the percentage of total IRDP innovation grants awarded over the 1983-1987 period to each industry.

We looked as well into the determinants of the generosity of the IRDP program, expressed as the ratio of grants actually obtained to eligible costs.

Explanatory variables

Although many empirical studies have demonstrated that a significant portion of new technology cannot be appropriated completely by its creators, a universally accepted direct empirical measure of appropriability has not yet been developed. The brief survey of the literature in the preceeding section suggests, however, several complementary and sometimes competing or overlapping proxies (indicators) of different aspects of appropriability (or the lack of it). The fact that most proxies are only weakly correlated among themselves suggests that on the one hand appropriability manifests itself on several different levels (e.g. intra and inter-industry spillovers on the national and international level) and on the other hand that there are still serious gaps in our knowledge and measurement of this phenomenon. Confronted with the lack of a universally accepted measure of appropriability, we opted for an eclectic approach. Instead of relying arbitrarily on a single proxy, we have experimented with several of them.

(a) Basic research (BRD) defined as "original investigation for the advancement of scientific knowledge . . . which does not have immediate commercial objectives". In view of the diffusion of scientific information, a large part of basic research is likely to be inappropriable. However, as Mansfield and others found, basic research contributes significantly to the productivity of firms.[35] Therefore one would expect that firms engaging in basic research do so because they hope to benefit from the scientific discoveries or other results of doing basic research in some way in the future. The inappropriable inter-industry spillovers from the basic research remain, however, significant. Thus even though firms active in basic research may do so for their own benefit, they may have difficulties to prevent other firms from sharing the results of their own scientific discoveries. The variable which takes account of basic research is the percentage of current R&D expenditure of the industry assigned to basic research, BRD.

(b) Inter-industry flows of technology as measured by patent statistics (DUL). McFetridge and Corvari have shown that the patent-based measures of technological self-sufficiency (which is the complement of the measure of technological inter-industry spillovers) for Canadian manufacturing industries are closely correlated with measures based on input-output weighted R&D flows in Canada and patent weighted R&D flows in the United States.[36] Ducharme and Mohnen's finding that the pattern of inter-industry patent flows in Canada did not change significantly from 1978 to the mid eighties suggests that the 1978 patent matrix may still be a relevant proxy for inter-industry flows of technology.[37] The percentage of Canadian patents most likely produced by industry i and most likely used by all other industries $j \neq i$, ($j = 1,29$) has been calculated from the matrix $[P_{ij}]$ of inter-industry patenting for 1978 from Seguin-Dulude and it is denoted DUL and is logarithm LDUL.[38]

(c)Effectiveness of patent protection (PATD and PATC). The third set of appropriability variables we experimented with were variables from the Yale questionnaire on R&D, kindly made available to us by Levin. The authors of the survey, Levin, Klevorick, Nelson and Winter (LKNW) asked industry experts in the United States to evaluate the effectiveness of various means of protecting the returns from R&D.[39] Given the criticism by Cockburn and Griliches[40], we used for our tests only the response to the question how effective are patents to prevent competitors to duplicate a new product, or alternatively, the same question related to duplication of a new process. The effectiveness is scored on a scale from 1 (not at all effective) to 7 (very effective), and we aggregated the mean scores to appropriate industry levels. The variable is designated as PATD for products and PATC for process. We believe that the technological similarity between the Canadian and the American industry is such that results of Levin's survey can be used in the Canadian context.

LKNW survey variables do not differentiate between intra and inter-industry spillovers, they implicitly include both. Using PAT variables as a complement to inter-industry patent flows DUL has the additional advantage of including in the analysis the effect of intra-industry spillovers. On the other hand, the appropriability proxies are to a certain degree overlapping; this is true not only for the LKNW variables among themselves, but for all proxies listed in (a), (b) and (c) above.

(d) Uninsurable risk (RAD). Introduction of new technology is risky. Owing to imperfections of insurance and capital markets innovating firms, especially those in pursuit of radical innovations, are often exposed to high uninsurable risk.[41] The proxy for R&D aimed at risky projects is the percentage of industry's current research expenditures devoted to a radical change, RAD.[42] RAD includes R&D aimed at new products, processes and technical services.

(e) The project size (ELM). Public support for a valid project too large for a small firm satisfies one of Arrow's justifications for public support to innovation.[43] The average project size, proxied by the "eligible cost for subsidy under the program" variable ELIM, will be used in our analysis of IRDP grants. Public support is justified if it is extended to projects whose size exceeds the capacity of the innovating firm; the variable is expected to have a positive sign.

(f) Other explanatory variables. The first that comes to mind is the size of industry. It is conceivable that grants are distributed in proportion to demand by industry, which in turn could be a function of the size of the industry. If this should be the case, larger industries would reap a larger share of total grants than the smaller ones. As there is no reason to expect that the size of an industry is associated with the occurrence of one or another form of innovation-related market failures, we should first eliminate the possibility that grants might be distributed according to industry size. The relative size of industry. SIZE (sales of industry i as a percentage of total sales of all industries) will be introduced in order to control for industry size.

The second competing hypothesis capable of explaining the industrial distribution of innovation grants rests on the complementary relationship between privately funded R&D (PRD) and government support for research. The effect of government support on private R&D depends however, on the particular form of government involvement. Government contract research performed in industry and to a certain extent also government-funded R&D done in government and in universities, influences private R&D positively.[44] On the other hand, an overhead allowance for private R&D expenditures shows, a weaker and delayed effect, or no effect at all.[45] Several studies have demonstrated that government subsidies to R&D in Canada induce additional private spending on research.[46] While it is recognised that government's support to R&D induces later additional private research expenditures, it has been demonstrated that the casuality may be reversed. Best examples are drawn from the analysis of the US Department of Defence procurement policies. Design competitions incite private firms to invest more in R&D in order to increase their chances of winning subsidised contracts for research and production of weapon systems.[47] Also, firms have learned that by increasing their company-funded spending on independent research, they improve their chances to increase the allowable (subsidised) R&D costs for later periods.

Finally, even if none of the above mentioned reasons for complementarity between private and public funding of R&D applies, industries performing more R&D could simply be more successful in lobbying for public support to R&D. The R&D intensity variable PRDS (R&D expenses financed by industry/sales) will be introduced in the regression to account for the possible effect of privately funded research intensity on distribution of R&D subsidies in later periods.[48]

Results of estimations

Total federal grants and contracts

The distribution of the total federal support[49] to R&D among Canadian industries and technical services does not appear to be associated in any way with any of the proxy variables for appropriability or risk. In fact, the only regressor which has any statistical relationship with the industry by industry percentage distribution of federal grants and contracts for R&D in 1987 is the intensity of privately funded expenditures research of the industry in the preceding period, 1985, presented in the first equation in Table 5. This relationship is unduly influenced by the heavy support received by one particular industry, which also happens to be one of the main spenders on R&D — the aircraft and parts industry. It received in 1987 almost half of total grants (48%). The observation for this industry is excluded from the second equation. The statistical association between an industry's share of total federal grants and contracts and its R&D intensity remains very significant but again, there is no relationship with any appropriability, risk and project size proxies.

Distribution of IRDP grants 1983-1987 by industry

Before examining the hypothesis that IRDP grants are distributed according to incidence of market failure, we wanted to see whether it

TABLE 5
INDUSTRY BY INDUSTRY DISTRIBUTION OF FEDERAL GRANTS AND CONTRACTS (1987)

$$\underset{}{FED} = \underset{(0.50)}{0.014} + \underset{(2.32)b}{0.007}\ PRD/S \quad R^2\ adj. = \underset{(F=5.39)b}{0.18} \quad n=21$$

$$FED^* = \underset{(1.19)}{0.014} + \underset{(2.18)b}{0.0038}\ PRD/S \quad R^2\ adj. = \underset{(F=4.77)b}{0.16} \quad n=20$$

Variables:

FED	Percentage of total federal grants and contracts net of DIPP grants
PRD/S	Privately funded R&D/sales
C	Constant

Note: * Aircraft and parts industry excluded.
The levels of statistical significance of the t and F statistics in parentheses below the coefficients are: a=0.01, b=0.05, c=0.1.

is necessary to control regressions for the size and/or the intensity of private R&D. Bivariate regressions and multiple regressions on appropriability, risk and minimum efficient size proxies (not presented here) with both SIZE and R&D/S variables suggest that we should reject the hypothesis that IRDP grants were distributed among industries according to their size or previous private expenditures on R&D.

As for the relationship between the share of IRDP grants received and proxies for appropriability, results are mixed.

First, the relative importance of basic research conducted by an industry (BRD) is not significantly correlated with its share of IRDP grants.

Now consider the information conveyed by the DUL variable which measures the patent spillover. It is highly significant (close of 1% level) for the total sample of manufacturing industries, in part because it is dominated by three industries that are the source of technology for the rest of the economy: non-electrical machinery, chemical products and other electrical products.[50] When one of several of these observations are deleted, the statistical significance of the LDUL variable declines, but remains statistically significant at the 10% level (see equation No.4). The positive sign associated with LDUL variable shows that a larger proportion of IRDP grants going to industries generating patent spillovers is in conformity with the theoretical rationale that industries generating spillovers merit public support. We note that other studies demonstrate that industries with high patent spillovers feed inventions to the rest of the industrial sector.[51]

TABLE 6
INDUSTRY BY INDUSTRY DISTRIBUTION OF IRDP GRANTS (1983-1987) AS A FUNCTION OF APPROPRIABILITY, RISK AND SIZE

No.	C	BRD	PATD	LDUL	RAD	ELIM	PRD/S	SIZE	R^2adj.	n
1	.06	−.003							0.05	
	(3.7)a	(−1.5)							(2.26)	25
2	.16		−.03						.08	
	(2.8)a		(−1.7)c						(2.82)	22
3	0.11			.017					.25	20
	(4.12)a			(2.72)b					(7.41)a	
4	0.09			.012					.12	19
	(3.09)a			(1.87)c					(3.5)c	
5	0.03				0.0002				−.03	25
	(0.70)				(.70)				(.12)	
6	0.019					2.04E-5			,15	22
	(1.4)					(2.17)b			(4.7)b	
7	.035						.0007		−.03	27
	(2.98)a						(.32)		(.11)	
8	−.004							.113	.03	21
	(0.11)							(1.32)	(1.7)	
9	.183		−.02	.017		1.39E-5			.39	20
	(2.63)b		(−1.47)	(2.91)b		(1.62)			(5.09)b	

Variables:

IRDP	The percentage of total IRDP grants awarded to an industry
BRD	The percentage of current R&D assigned to basic research
PATD	The mean score of the effectiveness of patents to prevent duplication of a new product
LDUL	The logarithm of the percentage of Canadian patents most likely used by other industries $i \neq j$
RAD	The percentage of current R&D assigned to radical change
ELIM	The average eligible cost of project size
PRD/S	Privately funded R&D/sales
SIZE	Sales of industry i as a percentage of total sales of all industries
C	Constant

Notes:
1. Equation #4 is estimated for a sample of manufacturing industries excluding the outlying observation which is non-electrical machines.
2. The levels of statistical significance of the t and F statistics presented in parentheses below the coefficients are: a=0.01, b=0.05, c=0.1,

The complementary proxy appropriability from the LKNW survey, the effectiveness of patents to prevent imitation of product innovations, PATD, appears with a persistently negative, although rarely statistically significant regression coefficient.[52] It suggests, in conformity with the appropriability hypothesis, that a larger share of IRDP grants is awarded to industries where the patent protection is relatively ineffective. Thus except for the basic research orientation, both remaining patent related proxies for appropriabily tend to support the hypothesis that IRDP grants were distributed more generously to industries that generate inventions used by other industries (inter-industry spillovers) and experience difficulties to protect their technology by patenting (intra and inter-industry spillovers).

The extent of R&D aimed at risky projects, represented in our regressions by RAD variable, does not appear to influence in any way the distribution of IRDP grants.

On the other hand, the size of the project measured by the variable ELIM, the mean grant-eligible cost for the industry, is one of the variables which appear to contribute significantly to explanation of the IRDP grant distribution. Is the positive relationship an indication of the tendency to support larger, riskier projects or is it simply a reflection of the tendency of firms presenting larger projects to sell better their ideas? Even though more concentrated industries tend to have projects of larger size we did not uncover any direct relationship between the distribution of subsidies and industrial concentration.[53] It appears that firms in more concentrated industries present larger projects but do not obtain financing more easily.

The ELIM variable in combination with LDUL and PATD accounts for a decent proportion (40%) of total variance and suggests that the origin of the project in one of the technology-source industries and the size of the project are probably the best explanation of the pattern of industry by industry distribution of IRDP grants. In addition, the persistently negative although rarely statistically quite significant coefficient of the PATD variable suggests that industries receiving a more generous part of IRDP grants tend to be those where patent protection is relatively effective.

Determinants of generosity of IRDP grants

The interindustry distribution of grants depends of course to a great extent on industry's demand for public support. One of the ways the granting agency can influence the distribution of grants, presumably in order to correct the more evident manifestations of market failure, is through the generosity of the grant relative to the eligible cost of the project. The ratio of IRDP grants to eligible project costs by industry is the dependent variable in the next model we experimented with. The independent variables are the same as the ones used in the two previous models.

Regression results are presented in Table 7. First, in contrast to previous specifications, the highly concentrated industries received on average grants covering a higher proportion of the project costs than the less concentrated ones. Grants received by industries generating technology spillovers, as indicated by the positive coefficient of the LDUL variable, covered a higher proportion of eligible project costs than grants obtained by beneficiaries of patent spillovers. Finally — and again the results suggest this only very tentatively — industries where patents are not a very effective means of appropriation received proportionally more public support from IRDP than other industries.

TABLE 7
GENEROSITY OF IRDP GRANTS
(Grant/Eligible cost)

C	*C4*	*PATD*	*LDUL*	*R^2adj.*	*n*
0.64 (3.2)a	0.003 (1.89)c	−.044 (−1.12)	.038 (1.97)c	.168 (2.2)	19

Variables:

C4	The percentage of industry's sales accounted for by the four largest enterprises
PATD	The mean score of the effectiveness of patents to prevent duplication of a new product
LDUL	The logarithm of the percentage of Canadian patents most likely used by other industries $i \neq j$

Note: The levels of statistical significance of the t and F statistics presented in parentheses below the coefficients are: a=.01, b=0.05, c=0.1.

CONCLUSIONS

1. The Canadian taxpayer is, by international standards, a generous supporter of research and development. The question arises whether her tax contribution to industrial R&D is distributed to industries and firms in a way that mitigates market failure.

2. A global look at federal financing of private sector R&D reveals that tax credits claimed passed in importance subsidies (grants) in 1984 and became more than twice as important, at about $780 million, in 1989 as the other form of assistance. Since tax credits are available to all firms performing research, it appears that on this global level appropriability, an important aspect of market failure, is of little concern to lawmakers.

3. At the industry level, however, the evidence is mixed. The industry-by-industry distribution of total federal R&D grants and contracts does not appear to be associated with any appropriability risk and/or indivisibility proxies. Before concluding, however, that there is no statistical relationship between an industry's share of total federal R&D grants and proxies for market failure, one should eliminate the possibiltiy that the reported absence of relationship might be caused by the inclusion of contracts in the FED variable. The data that would make this test possible were not available. On the other hand, the analysis

of the industry breakdown of IRDP grants suggests that "technology feeding" industries — which provide their downstream customers with substantial spillover benefits — receive more grants than "technology receiving" industries. The IRDP grant-receiving industries tend also to have difficulties in appropriating returns from R&D through patent protection, and their projects are of a relatively large size.

4. The next push in the investigation of this area should be in the direction of tax credits. If data by industry could be obtained, analysis should reveal whether this principal source of assistance to research is, perhaps unwittingly, taken advantage of by "deserving" industries.

Spillovers and inappropriability are currently receiving a lot of attention. Research in this area should be connected to enquiry on the effectiveness of government subsidies to innovation, both on domestic territory and in international joint projects.

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12. Grant statistics are derived from Statistics Canada surveys of research-performing private and crown-owned firms. The reports by recipients do not always match the figures of the granting ministries or agencies, perhaps chiefly due to timing discrepancies. Tax statistics refer to tax credit *claims,* rather than refunds. These have also been compiled from surveys, but only until 1985. From 1985 on they are compiled by Revenue Canada on the basis of income tax returns rather than R&D performance surveys. It is impossible to say how this more comprehensive reading affects the consistency of the tax claim series. Claims, in the absence of taxable profits, may be carried forward against (quite remote) tax liabilities. In addition, not all claims may of course be allowed. Knowledgeable sources estimate that ten or fifteen per cent of the claims — not of the total sums — are disallowed.

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14. Among the references consulted were the Science Council of Canada, *Reaching for Tomorrow-Science and Technology Policy in Canada 1991,* Ottawa, 1992; S. McInness, 'Setting science and technology policies in Canada'', in B. Grousse *et al.* (eds), *Science and Technology Policy Evaluation,* Presses Laval, Québec, 1990 and *The Budget,* tabled February 16, 1991, Ch. 7.
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16. Industry, Science and Technology Canada (ISTC), *Support For Technology Development,* Ottawa, 1989, p. 9.
17. Tarasofsky, *op. cit.,* p. 40.
18. M. Atkinson and R. Powers, 'Inside the industrial policy garbage can: Selective subsidies to business in Canada', *Canadian Public Policy,* 13, 2, 1987, pp. 208-17.
19. D. Horsley *et al., Industrial Assistance Programs in Canada,* Toronto: CCH Canadian Limited, 1985, 80-560 and 80-575 and Office Consolidation, *Industrial and Regional Development Act and Regulations,* Ottawa, February 1985.
20. Z. Griliches, 'Issues in assessing the contribution of research and development to productivity growth', *Bell Journal of Economics,* 10, 1, 1979, pp. 92-116.
21. The innovator would capture all returns to his innovation if he could extract the total consumer surplus through perfect price discrimination. Price discrimination is, however, usually infeasible for legal or practical lessons.
22. For the United States, consult N. Terleckyj, 'Direct and indirect effects of industrial research and development on the productivity growth of industries', in J.W. Kendrick and B. Vaccara (eds), *New Development in Productivity Measurements,* Chicago University Press for NBER, Studies in Income and Wealth, 44, Chicago, 1980 and F. Scherer, 'Inter-industry technology flows in the United States', *Research Policy,* 11, 1982, pp. 227-45. For Canada, see H. Postner and L. Wesa, *Canadian Productivity Growth Analysis,* Economic Council of Canada, Ottawa, 1983; P. Hanel, 'L'effet des dépenses en R&D sur la productivité du travail au Québec', *L'Actualité économique,* 64, 3, 1988, pp.396-415.
23. Z. Griliches, *op. cit.*
24. The means of access to new technology vary from completely legal exchange of scientific information or personal contacts and mobility, through reverse engineering and copying, down to illegal industrial espionage.
25. The spillovers are commonly estimated in a cost function model c = C(y,v,S), where c is the cost of production, y the vector of factor prices and S a vector of spillover variables. Factors include own R&D capital.
    The interindustry spillover is $S_i = \sum_j W_{ij}.R_j$ where R_j, is the stock of knowledge available in other industries j, and W_{ij} the weighing function, i.e. the actual fraction of knowledge originating in industry j and borrowed by industry i. The intra-industry spillover is defined in an analogical manner.
26. The existence of inter-industry differences in propensity to patent documented by F. Scherer, 'The propensity to patent', *International Journal of Industrial Organisation,* 1983, pp. 107-8 and an international comparison based on Canadian patent data by A. Englander *et al.,* 'R&D, innovation and the total factor productivity slowdown', *OECD Economic Studies,* Autumn 1988, pp. 7-42 indicates that the patent spillovers matrices are a very imperfect proxy for technology flows in general and for R&D spillovers in particular. This led I. Cockburn and Z. Griliches, 'Industry effects and appropriability measures in the stock market's valuation of R&D and patents', *American Economic Review,* Papers & Proceedings, 78, 2, 1988, pp. 419-23, to the conclusion that the data on R&D measures are stronger measures of input than patents are of output of the innovaton process. In spite of statistical shortcomings of patent data, the patent classification represents the richest source

of technical information and, therefore, can be used to characterise the firm's position in the technology space. Assuming that firms patenting in the same patent classes are technologically close, A. Jaffe, 'Technological opportunity and spillovers of R&D: Evidence from firm's patents, profits and market value', *American Economic Review*, 76, 5, 1986, pp. 984-1001, characterised a firm's position in the space of patent classes. He found that R&D productivity is increased by the R&D of "technological neighbours", though neighbours' R&D lowers the profits and market value of low R&D intensity firms. Firms are shown to adjust the composition of their R&D in response to technological opportunity.

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30. E. Mansfield *et al.*, 'Social and private rates of return from industrial innovations', *Quarterly Journal of Economics*, 91, 2, 1977, pp. 221-40.
31. P. Hanel, *op. cit.*, p. 411.
32. F. Scherer *(1982) op. cit.* and N. Terleckyj, *op. cit.*
33. Owing to the very limited number of industries for which the amount of federal grants is disclosed (12 out of 21 manufacturing industries) the grants had to be lumped together with federal R&D contracts in order to increase the number of usable observations to 20. Even though the increase of the sample size is desirable for statistical purposes, by adding federal contracts to grants we commit a specification error, because R&D contracts are more likely to be awarded for "public service" reasons rather than as a remedy to market imperfections. The grant cum contract dependent variable is therefore an inferior specification for a test of appropriability and other types of market failure. Source: Statistics Canada, *Industrial Research and Development Statistics, 1987*, Catalog No. 88-202 Annual.
34. The information from annual reports on Industrial and Regional Development Programs was supplemented by a custom-made computer listing kindly made available by the Department of Industry, Science and Technology.
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38. L. Séguin-Dulude, *op. cit.* pp.278-79. This variable takes into account only the spillovers to first users; ideally, it should be possible to take into account the inter-industry ramifications in order to include the total downstream effect. Another limitation of variable DUL is that it is based on the judgement of experts in the patent office rather than observed facts. For a significant proportion of patents, especially for very pathbreaking inventions, the industries most likely to produce and/or to use them may not even exist and cannot be determined.
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46. D. McFetridge, *op. cit.*, A. Tarasofsky, *op. cit.*
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49. The results do not change significantly whether contributions made under the Defence Industry Productivity Program are included or not. The relative size of the industry is not a factor either.
50. The DUL variable for the Other electrical products category includes also electronic parts and other electronic equipment.
51. J. Hartwick, *op. cit.;* J. Bernstein, *op. cit.;* P. Hanel, *op. cit.;* to cite only a few.
52. The effectiveness of patents to prevent imitation of process innovations PADC was never statistically significant and results are not presented in Table 6.
53. ELIM is positively correlated with C4 concentration ratio but subsidies are not.

$$\underset{(.22)}{\text{ELIM} = 116.6} + \underset{(2.1)\text{b}}{20.9\ \text{C4}} \qquad R^2\text{adj.} = .13\ (F=4.2)\ n=22$$

$$\underset{(.95)}{\text{IRDP\%} = 0.02} - \underset{(-.19)}{0.001\ \text{C4}} + \underset{(2.0)\text{b}}{2.1\text{E}-0.5\ \text{ELIM}} \qquad R^2\text{adj.} = .11\ (F=2.3)\ n=22$$