DRAFT FOR COMMENTS

REVIEW OF CANADIAN ACADEMIC PHYSICS

Economic Impact Study

Paul S. Vincett
President, FairCopy Services, Inc., a Xerox Company
NSERC Group Chair, Physics

August 13, 1997

EXECUTIVE SUMMARY

This first public draft of the Economic Impact study of the Review of Physics presents a nearly complete text. The economic impact numbers themselves are still somewhat preliminary, and some further discounted cash flow calculations also remain to be done. However, the broad outlines of the likely conclusions now seem clear. General comments are solicited. Specific areas where factual input would be helpful (on certain spin-off companies and on international student percentages) are also indicated *in italics* in sections 3.2 and 6.4.

The Economic Impact study attempts to quantify, as far as possible, a range of direct Canadian economic impacts which would not have occurred without NSERC support of physics via the Research Grants program. For a variety of reasons, not least the difficulty of attribution to any one national effort, the study cannot attempt to quantify some of the more indirect but very large impacts of international physics, like those flowing from the physics underlying the invention of the transistor or the laser, or the physics underlying major instrumentation and methodology advances such as NMR, magnetic resonance imaging, ion implantation or the World Wide Web. Despite the omission of such enormous impacts, we believe that it is of great importance to establish whether, even without these long-term international effects, the Canadian impact of Canadian physics is still large. The study concludes that it is. The long-term international effects can then be considered as a very large bonus added to an already excellent investment.

The study attempts (i) to consider and compare a wider range of impacts than most previous studies, including the economic impact of graduate student training, (ii) to explicitly consider the incrementally of the impacts, (iii) to compare government expenditures with economic impacts on a reasonably equivalent basis.

Rather detailed arguments are presented to suggest that the NSERC physics Research Grants effort (which accounts for about $35M of NSERC's annual budget) conservatively generates present or future primary economic activity having a present value roughly equivalent to government expenditures of about $240-270M. If consumer multiplier effects (the recirculation of money as it is spent by its original recipients) are considered, all these numbers are probably multiplied by a factor of 3 – 5. The largest impact appears to be from spin-off companies, which probably account for about half of the above numbers, even without considering second-level spin-offs. The next largest effect is probably the economic impact of graduate student training, which is estimated to be roughly 15-20% of the total. Other impacts considered include technology licensing and the impact of spending by international students. Medium-term impacts on existing companies (other than via technology licensing) cannot be estimated by a study of this scope, but arguments are presented to suggest that this may be another large impact which is not included in the above numbers. The impact of the Research Grants program in enabling concurrent or later Research Partnership efforts is also not included.

Reasonably accurate comparisons can be made with other disciplines only for spin-off companies, but this is by far the largest impact. The revenues of physics-generated companies, as a percentage of revenues associated with all NSERC disciplines, is 25% higher than physics' share of the Research Grants budget, despite the rather basic and long-term nature of much of physics. The share for Condensed Matter/General Physics (about 12.5% of the revenues from all disciplines) is more than twice its share of the Research Grants (6.1%), and for Space Physics the ratio is over 10:1. For physics as a whole, the dollar revenues are well over three times the annual physics Research Grant budget.

The present study, while rather broad in scope, is approximate and, of course, primarily addresses physics. Major NSERC studies are therefore recommended to better quantify several of the impacts for the NSERC disciplines as a whole. These include medium-term impacts on existing companies (studied by Mansfield in the U.S.), the growing impact of technology licensing, the economic impact of graduate student training, and the impact of international student teaching. This could help greatly in making a still better short- to medium-term economic case for the NSERC Research Grants program.

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ECONOMIC IMPACT STUDY OF THE REVIEW OF PHYSICS

1. INTRODUCTION

The objective of this Economic Impact study is to quantify, as far as possible, a range of direct Canadian economic impacts which would not have occurred without NSERC support of physics via the Research Grants program. Such a focus is clearly of great importance from a policy standpoint, but it has both positive and negative impacts on the estimates which will be made. From the negative standpoint, it largely prevents consideration of the broad, enormous, long-term effects of international physics, since these effects (in addition to the problems mentioned below) could be argued not to be dependent on any one national endeavour, at least those of smaller countries. In effect, one is limited to consideration of the impacts of Canadian physics on Canada, ignoring 'cross-terms', namely the impact of Canadian physics on the rest of the world and the impact of non-Canadian physics on Canada. On the other hand, this focus does permit us to consider (with due caution) impacts for which the NSERC Research grants program may not have been a sufficient condition, but for which we can argue that it was necessary and critically important. In any event, we believe that this focused approach, in addition to being reasonably tractable, is precisely the one of most relevance to answering policy questions as to the short- and medium-term importance of NSERC physics Research Grants to Canada.

It should be strongly emphasized once again that a study of this type cannot, for a variety of reasons, attempt to quantify some of the more indirect but very large impacts of international physics, for example those flowing from the physics underlying the invention of the transistor or the laser, or the physics underlying major instrumentation and methodology advances such as NMR, magnetic resonance imaging, ion implantation, neutron scattering or the World Wide Web. Most observers would acknowledge the seminal contribution of physics to advances like the transistor (and hence to the computer revolution) and the laser, to give just two examples. However, instrumentation advances based on physics are often seriously understated: as pointed out recently [1], "*instrumentation flow*" is *"particularly strong from physics to chemistry, as well as from physics and chemistry to biology, clinical medicine and ultimately health-care delivery*". Reference 1 goes on to mention spectroscopes, electron microscopy, X-ray crystallography and NMR, and points out that NMR, for example, was pioneered by physicists who were trying to measure the magnetic moments of atomic nuclei, an innovation for which they received the Nobel prize in physics. Similarly, methodologies originating in physics play major roles in industry and the economy. Reference 1 points out, for example, that ion implantation originated with high-energy physics. A very recent and important example is the World Wide Web, which also originated with high-energy physics.

The reasons why a study of the present type cannot attempt to quantify impacts of the type mentioned above include (i) the difficulty of attributing such large and diverse impacts to specific national programs, as previously mentioned, or even to specific disciplines, (ii) the difficulty of measuring the impacts, (iii) the frequent need for large and uncertain discounting factors (related to the time value of money, section 1.5) to allow for the delay between the initial work and the large applications, and (iv) the possibility of objections, right or wrong, that the effects of relatively old science may not be a reliable guide to the present situation. Despite this omission of what are certainly enormous impacts of physics, we believe that it is still of great importance to establish whether, even without these long-term effects, the Canadian impact is still large. We shall conclude that it is. The long-term effects can then be considered as a very large bonus added to an already excellent investment.

The study attempts (i) to consider and compare a wider range of impacts than most previous studies, including the economic impact of graduate student training, (ii) to explicitly consider the incrementality of the impacts, (iii) to compare government expenditures with economic impacts on a reasonably equivalent basis.

We now turn to this last point.

1.1 Comparing Apples with Apples: The Canadian Situation

The last point above is nontrivial and, remarkably, it is usually not explicitly considered. For example, in comparing expenditures with impacts, does one compare NSERC expenditures with spin-off company profits, taxes paid, revenues or something else? How does one measure the impact of licenses? What measure does one use for the impact of graduate student training? Very frequently, these points are glossed over in economic impact studies. Additional salaries generated by higher education, for example, are often compared directly with government expenditures on universities, with no stated justification; likewise, expenditures on R&D are variously compared (often without explicit justification) to either corporate profits or to revenues, sometimes to both in the same paper! As we shall argue below, we believe that, in Canada, government expenditures can properly be compared, to first order, with incremental Canadian corporate or other business revenues; we shall occasionally refer to such revenues and their analogs as 'primary economic activity.' While in one sense it might seem intuitive that the value of an innovation would be just the additional profits resulting from its use (and, in some case, this would be reasonable), in fact the use of revenues in appropriate circumstances is not at all unusual (see references 3 and 4 for just two examples).

When a government makes an expenditure in Canada, regardless of whether it is a social program, a procurement of some goods or services or even an NSERC expenditure, it injects that amount of 'primary' cash into one or more regions of Canada. In most cases, that money will be spent by the recipients primarily in Canada, whether it is to buy food, shelter and the like in the case of a social expenditure, or to purchase materials, employee time etc. by a company, or to support a graduate student and buy materials in the case of an NSERC grant. The second-level recipients of the cash will then spend the money on other such items and so on. At each stage, there is some 'leakage' out of Canada (some of the purchased items will be imports), so that the process eventually converges. The process of recirculation of the original cash gives rise to a 'multiplier' effect of the initial government expenditure. The magnitude of this particular multiplier, which we will refer to as the consumer multiplier, varies depending upon the economic region under study (money will leak faster out of B.C., say, than out of Canada) and will also depend on the nature of the original expense. For jurisdictions of the size of countries or major Provinces, these multipliers can typically be in the range of 2 to about 5 or so (see [5] for example), even allowing for the initial recipient's foreign purchases.

It is obvious, then, that a non-capital initial government expenditure of $X will create first-level economic activity of $X, largely in Canada, followed by multiplier effects. If the initial outlay is balanced by a reduction in a government transfer to another program or region, the effect of this will be -$X, so that (if multipliers are similar), the net effect is zero as would be expected. However, if the expenditure is of a capital nature (building the Trans-Canada Highway, transferring money to a Province to build a hospital, supporting research, etc.), there may well be additional benefits in later years.

With this introduction, it seems clear that if one wishes to compare the original government expenditure with the subsequent effect, one can ask how much additional 'primary' cash is injected into the Canadian economy from that subsequent effect. If the subsequent effect is mainly the creation of additional business revenues, and <u>if those revenues are primarily from exports and if they do not merely replace an export which would have continued anyway</u>, then clearly the corporate revenues (assuming they are spent largely in Canada) are analogous to an equivalent government expenditure: they both inject a primary cash amount equal to the business revenue, and they are both subject to the consumer multiplier effects mentioned previously (although the exact magnitude of the multipliers may be different). In fact, to compare the amounts on an equivalent basis is probably a conservative assumption: high-tech corporate multipliers are probably [5] higher than typical 'low-tech' government expenditures. Reference 5, for example, argues that conservatively the multiplier for corporate revenues is about 3 and could be 4 - 5, and that for most other types of income it is about 2.0-2.5. Reference 6 suggests a multiplier of 2.5 to 3.5. Since both these references are for B.C., the Canadian numbers would be expected to be somewhat larger: expenditures may leak out of B.C., but remain in Canada.

We emphasize again that this rather simple approach (which allows us to largely ignore the effects of consumer multiplier effects, assuming they are not too different for different kinds of government expenditures) probably only works if the corporate revenues involved are incremental exports. If they simply replaced one revenue with another, or if all revenues were internal to Canada, then the value of new corporate products would possibly be more similar to the additional profits than to the revenues. Fortunately, the incremental export assumption is likely rather good for Canadian high-tech firms: most of these firms sell primarily into an international market and have a very high proportion of exports.[a] Even if a particular technical innovation merely replaced one product with an improved one, it can be argued [7] that failure to do so would likely quickly lead to loss of the market to a foreign competitor. Furthermore, in high-tech situations, even products sold to Canadian customers would probably have been purchased from foreign suppliers in the absence of the Canadian firm. Thus, we appear to be rather safe in treating most Canadian high-tech revenues as in essence 'new' money for Canada. In this sense, the Canadian situation seems to differ greatly from that in the U.S. (from where the majority of economic impact studies on R&D originate). Clearly, it is far less likely in the U.S. that most revenues would be exports.

The incrementality of most Canadian high-tech revenues also justifies the assumption, already implicit in at least one NSERC study on spin-off companies [18], that one can reasonably recognize the full revenues of a spin-off company in a study of the impacts of scientific work, even when some or most of those revenues may come from later advances or different business areas. The later areas might indeed have been developed by others in the absence of the company in question, but the chances are high that they would not have been Canadian. Thus, such revenues are still incremental and would not have occurred without the original NSERC work.

To repeat, we believe that an incrementality assumption is a rather good one for Canadian high-tech businesses: in most cases, new revenues will (i) relate to a completely new product, (ii) create new international markets, and/or (iii) protect or establish Canadian revenues which would otherwise go to non-Canadian companies. We can then seek to compare 'apples to apples' by comparing injections of government money with injections of money from such businesses. The latter will be nearly equal to the corresponding business revenues. Even where businesses in the usual sense are not involved, we will use similar considerations to try to maintain the 'apples to apples' nature of the comparisons. This means that, for the bulk of our analysis, we will be conservative when we ignore consumer multiplier effects, since these would apply to both kinds of cash injections, with the high-tech ones probably having somewhat higher multipliers.

1.2 Second-Order Effects

There will certainly be a few cases where there may be incomplete incrementality or other factors which could conceivably bias our estimates upwards somewhat. For example, some companies may employ foreign sales forces, which do not spend their earnings in Canada, or they may purchase unusually large amounts of foreign raw materials. However, effects of this type are likely to be far smaller than the conservatism introduced by one key aspect of our analysis, and of most studies which search for fairly direct economic impacts of R&D. This is that we very largely ignore second-level impacts.

[a] For example, more than 95% of the revenue of the largest spin-off company in section 3 comes from exports.

Second-level spin-off companies provide a good example of impacts which will therefore be neglected. By this we mean companies which spin-off, not from a university directly, but from the original spin-off company itself, or perhaps even from a second-level spin-off. An informal study by the University of Saskatchewan Physics Department, for example, found [8] that just one of the companies (SED) in our spin-off study (section 3) has spawned approximately 20 additional companies in Saskatchewan! Another study [9] indicates that in Cambridge, England, which has produced many spin-offs, the first generation companies accounted for less than 40 companies in the 1980's, while the later-generation companies already numbered over 200, including some of the most important ones!

A different class of second-order effects occurs via what is often (and confusingly) referred to as the 'social' return, even though it has nothing to do with consumer multiplier effects. Rather, this refers to the conclusion of many studies ([10-12] for example) that the impact of an innovation on primary economic activity is far higher than the impact on the innovating company, because the improved products and processes reduce the costs to consumers and also (although this is not entirely without controversy [13]) improve the economic performance of companies which purchase products from the innovator. This, of course, is an excellent reason why governments, and not just corporations, should support R&D. One study [11], for example, investigated a range of innovations and estimated that the average 'private returns' (i.e. returns to the innovating company) were 25% and that the social returns were 56%. Moreover, in many of the cases studied, the rate of return to the innovating company was very low, but the social rate was high; in one case, for example, the private rate of return was 4%, but the social rate of return was 116%![b]

It is obviously very difficult to estimate the additional impact of such effects without very detailed and time-consuming case studies. In anything other than a very comprehensive and expensive work it seems best to merely note that they certainly exist and to remember that the inherent conservatism so caused should much more than make up for any overestimates which could creep in.

1.3 The Nature of Economic Analyses

Since many physicists may not have been exposed to detailed economic analyses, it may be worth setting the stage in terms of what can and cannot be expected from studies of this type, especially those concerned with matters as complex as the impact of R&D. As is immediately apparent from any review of the literature, the kind of precision routinely expected in most scientific analyses is simply not possible in most economic studies of this type. The range of factors influencing even the simplest economic quantities is so large, and their interactions so complex, that one is doing well to make estimates to within an uncertainty of 25%. Very often, the best that can be done is to estimate quite broad ranges for many of the factors needed to make a final calculation, and to try to be sufficiently conservative that one will tend to underestimate the desired effects rather than seriously overestimating them. This is the approach followed in this study.

In many cases, the analysis could no doubt be refined, at significant cost, by obtaining more accurate data. However, even without these further studies, which are beyond our resources, we hope that the data will give at least approximate estimates of the impact of NSERC-supported physics where, in many cases, none seems to have existed before.

1.4 Returns on Investment

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[b] It may not be appropriate to consider most of this particular class of secondary effects in a review of the Canadian impacts of Canadian research, since (given the international markets of high-tech companies) most of them would presumably accrue to non-Canadian companies; meanwhile, the Canadian impact of non-Canadian innovations is not a direct result of NSERC. As before, we are probably constrained to neglect such 'cross-terms.' This does not apply to second level spin-offs, however, so long as they are Canadian.

There have been many studies of the return on investment from various kinds of R&D, and we shall refer to some of them in the sections which follow. Most of these relate to the apparent returns on industrial R&D, although a few widely quoted studies attempt to address the returns on basic research. A particularly well known example of the latter is the work [10] by Mansfield in the U.S. which suggested a return of 28% on university R&D, based on new product introductions in a certain period. Most of the estimates, however, are based on extremely broad and detailed U.S. studies of the impact of industrial R&D on multiple industries, or of the whole economy[c], and usually show very good (very often >40%) social returns.[d] While Canadian equivalents of these studies would be of interest, they are certainly far beyond the resources of this work. Furthermore, much of this work is subject to significant and fundamental criticisms ([2], for example), and the assumptions made are often questionable [4].

We shall not attempt rate of return calculations in this study. This is because (i) such calculations require detailed knowledge of the time-dependence of the impacts involved, and in most cases these are not available without great effort, (ii) even more seriously, it is very difficult to estimate the investments made, over and above the initial R&D, by entities other than NSERC in bringing products and services to market, (iii) such calculations are really not needed in order to estimate the economic impacts for which NSERC was a necessary but not perhaps a sufficient condition, which is our goal. In essence, we would rather attempt to answer this latter question with some degree of rigor, rather than attempting to generate a single rate of return number which, while apparently simple to understand, would likely be misleading.

1.5 Discounted Cash Flow and Present Values

Very often, activities undertaken and paid for today create impacts and benefits in the future. In order to compare the impacts with the initial expenditures, we shall several times need to employ 'discounted cash flow' calculations. These simply recognize that $1 received in say ten years is worth less than $1 received now. The calculations are done by discounting the income received in the future by a discount rate, which is related to appropriate interest rates. This discount rate is compounded over the number of years involved. For example, if a discount rate of 10% p.a. were chosen, the present value of $1 received in 10 years time would be $1/(1.1)^10, or $0.39; in other words, $0.39 invested now at 10% p.a. would yield $1 in 10 years' time.

Similarly, one can calculate the present value of a past expenditure by multiplying it by a similar factor. Similar to the example given above, the present value of $1 spent 10 years ago, assuming a 10% rate, would be $1*((1.1)^10), or $2.59.

We shall generally use a discount rate equal to the inflation rate plus 3%, which is historically a typical real rate of return for low risk, medium- to long-term investments; it has been used, for example, in earlier studies [34] on the impact of undergraduate training. In some cases, the impacts may themselves escalate by the inflation rate or some other rate. This rate must then be subtracted from the discount rate used. For example, if the stream of impacts was constant from year to year, after inflation, then the inflation rate would cancel out and the net discount rate applied would be 3%.

1.6 The NSERC Physics Research Grants Budget

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[c] Many of these are statistical correlation (rather than causal) 'econometric' studies of the relationship between R&D performance (mostly by industry) and financial performance indicators, such as productivity [14]. There have been suggestions [15] that, even for work carried out in industry, basic or long-term research is much more important as a productivity determinant than applied R&D.

[d] See section 1.2 for an explanation of the meaning of social returns.

In order to compare NSERC physics Research Grants with the impacts flowing from them, we must obviously know how much is spent. This is slightly less straightforward than might be expected, given the program elements (Major Equipment, Major Installations, MFA, etc.) which are typically not reported as part of the discipline totals and which may fluctuate substantially from year to year in any given discipline.

To avoid biases based on recent budget variations, we have for the present used average budget numbers [23] for the period 1986-96, the longest period for which we have been able to obtain accurate numbers. In fact, the results obtained from this are only very slightly different from the most recent numbers. The annual Sub-Atomic Physics (SAP) budget was calculated as simply the average of the total envelope (and pre-envelope) expenditures in these years [24]. For the other GSCs, 'operating' grants and equipment grants were added together. To allow for other Research Grant program elements which are not easily attributed to specific GSCs, we uplifted the non-SAP totals by 10.5%: 1.105 is [23] the ratio of (Total Research Grants expenditures for all disciplines except SAP)/(Total of all Operating plus Equipment Expenditures, except SAP). For GSC 17 (Space and Astronomy), we roughly removed the astronomy portion, by multiplying the total GSC numbers by 25.5%, which is equal [24] to the 1996 ratio of (grants held by non-astronomers in GSC 17)/(total GSC 17 grants). The total physics Research Grant budget so calculated is about $35M p.a. Table 1 (section 3.1) gives a break-down between physics sub-disciplines.

For some purposes, such as comparisons of NSERC expenditures with the revenues of spin-off companies (some of which were established 20-25 years ago), we shall need to estimate previous years' physics Research Grant spending and convert it to present values (section 1.5). We have not been able to obtain precise physics Research Grant numbers for years prior to 1986, but we have found sufficient data in previous reviews of physics that we should be able to make reasonable estimates. These calculations will be completed in time for the final report.

Depending upon how one wishes to utilize the results of the present study, one might recall that there seems to be general agreement that universities contribute a roughly equal amount of 'infrastructure' support to the work supported by NSERC. For some purposes, therefore, one might wish to compare the impacts discussed below with the NSERC grants plus the infrastructure support, or with roughly $70M p.a. rather than $35M.

We now turn to the various categories of economic impact which we believe we can estimate.

2. THE DIRECT IMPACT OF THE EXPENDITURE ITSELF

In common with other capital expenditures by governments, there is a direct impact of NSERC expenditures, equal to the expenditure, followed by the longer-term impacts [16]. (To first order, if the expenditure were non-capital, there would simply be no longer-term impacts.) That is, the initial expenditure creates incremental economic activity (salaries, construction, etc., together with normal consumer multiplier effects) comparable to the impact of a similar direct expenditure on a different program, such as a social payment, government procurement, etc. Of course, if the expenditure is offset by an expenditure cut elsewhere, the net result will be (to first order) zero. The point, however, is that the direct economic activity flowing from the R&D expenditure is additional to the spin-offs from the actual research.

This direct impact, while in a sense trivially obvious, is frequently neglected. It virtually guarantees that government expenditures on R&D must be at least as cost-effective as most forms of non-capital expenditure, which probably includes most government programs.

3. THE IMPACT OF SPIN-OFF COMPANIES

This is conceptually one of the easier impacts to measure, since this output of R&D gives rise directly to Canadian corporate revenues, which, as we have argued, can be compared almost directly with the underlying government expenditure. The impact of spin-off companies can be high, although there is some tendency to downplay it in some recent work [2]. In the U.S., for example, a recent report [17] concludes that if the companies founded by MIT graduates and faculty formed an independent nation, that nation would have the 24th largest economy in the world!

3.1 "Research Means Business"

Our primary analysis focuses on a 1995 study [18] by NSERC, which attempted to identify all known cases of for-profit spin-off companies related to NSERC-supported researchers in all disciplines, and having more than 5 employees. That is, there was no attempt to artificially balance the number of companies by region, discipline, etc. [19]. Some of the companies were actually started by graduate students of the researcher in question, although a cursory review of the companies suggests that spin-offs of this kind may have been substantially underestimated[e]. The study is very helpful, since it relates to all NSERC disciplines and thus allows comparisons between disciplines. An NRC database [21] of spin-off companies is in broad agreement with this study, although it identifies some additional companies, as we shall discuss later.

The following data on the physics related companies has been derived from this study[f] and compared with the Research Grants budget (section 1.6) for the physics disciplines and for all disciplines. In assigning companies to GSC areas, we tried to identify the discipline most closely associated with the NSERC researcher involved.

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[e] For example, one study [20] of Canadian firms founded by 'academic entrepreneurs' found that fully 45% of them were founded while the founder was a student, PDF, RA, etc. 16% of the total were founded by Masters' students and 10% by Ph.D. students.

[f] Twelve physics-related companies are involved out of 82 (from all disciplines) featured in the NSERC report: CTF Systems, Dewey McMillin, Moli Energy, Quantum Technology, Solar System Assemblies, TIR Systems, Vortek Industries, ITRES Research, SED Systems, Optech, Sciex, and Waterloo Scientific. The key founder of Sciex (Barry French) had been supported by two GSCs, one of them Physics [22]; only 50% of the Sciex revenues were therefore counted in this study. For six of the companies (representing 32% of the finally calculated revenues), only employee (rather than revenue) data was available. In these cases, we followed apparently the same estimating procedure as used in the NSERC report: the average revenue/employee for the other companies in the report ($127K) was multiplied by the number of employees of the company in question.

Table 1. Spin-Off Companies in '*NSERC Means Business*'

Source of Work (Sub-Discipline)	**General/ Condensed Matter Physics**	**Space Physics**	**Sub-Atomic Physics**	**Total Physics**	**All NSERC Disciplines**
Total Spin-Off Company Revenues p.a. ($M)	74.8	33.9	--	108.7	600
Research Grants, inc. Equipment and allowance for all other programs, p.a. ($M)	15.0	1.3	19.8	36.1	244.9
Company Revenues as % of all disciplines' companies	12.5%	5.7%	--	18.1%	100%
Research Grants as % of all disciplines	6.1%	0.54%	8.1%	14.7%	100%

The above data is important for at least two reasons:

(i) Despite the basic and long-term nature of much of physics, all but (arguably) the most basic subdiscipline (Sub-Atomic) has a much higher percentage of the spin-off revenues than its share of the Research Grant total. General/CMP has over one-eighth of the revenues from all disciplines, but only 6% of the grants. The situation for Space is even more remarkable: 5.7% versus 0.5%. Even including Sub-Atomic, the physics-related revenues as a whole are 25% higher than physics' share of the Research Grants.

(ii) Again excluding Sub-Atomic, the annual dollar revenues are about five times (Condensed Matter/General Physics) to 25 times (Space Physics) the corresponding annual NSERC expenditures! For physics as a whole, including Sub-Atomic, they are still three times higher.

While this analysis does not yet consider the delay between research and revenues (it is in essence a 'steady'-state comparison), this is a remarkable result for only one impact. Again, recall that we believe these numbers (revenues and NSERC expenditures) to be comparable; taking General/CMP as an example, this one impact appears to be roughly equivalent to a government expenditure of $75M p.a., when in fact NSERC is spending only about $15M p.a.[g]

The final report will try to take account of the delay between the NSERC expenditures and the revenue flows, as well as the time taken for the revenues to grow to their present levels. This will be done by converting NSERC physics Research Grants over the past 25 years or so to their present value. The growth of the spin-off company revenues to-date will be approximated by a simple geometric formula and converted to present values, and the same thing will be done conservatively for the companies' likely future revenues. The present values of the revenues will then be compared with the present value of the Grants. Very preliminarily, it does not seem likely that the ratio of impacts to expenditures will change dramatically. This is because the

g It could conceivably be objected that the numbers in Table 1 are heavily weighted by a small number of fairly large companies. However, recall that we have not treated them as a sample, which could have been subject to an inappropriate gross-up. The numbers are simply the sum of the actual companies. That a few large companies would be critically important is merely a reflection of the widespread '80/20 rule'. In fact, in our case the top 20% (2 companies) accounts for only 59%. The largest company has just under 30% of the total revenues.

discounting effects associated with the delay between research and revenues seem likely to be very roughly offset by the effects of future revenues.

3.2 Other Revenues

We have roughly updated the above revenues to allow for subsequent company growth (the NSERC numbers are from 1994/5) and to include some other companies. Of course, it is not possible to compare this additional data with all-discipline numbers.

Focusing first on the companies which appear in the NSERC report, we have been able to find more recent numbers on the World-Wide Web for companies representing 75 % of the revenues in Table 1. Conservatively assuming all other revenues have remained unchanged, we estimate recent total revenues to be $130M (3.6 times the annual NSERC physics Research Grants). These numbers break down into $88M for Condensed Matter/General Physics and $42M for Space Physics (respectively 6 and 32 times the corresponding Research Grants budgets).

Even these numbers may be conservative. Denys Cooper of NRC's IRAP program maintains a major database of university spin-off companies, and does not include companies started by graduate students or via faculty consulting. He has pointed out [21] that if one includes all companies whose products are primarily based on physics, regardless of the key professor's department or GSC, then (even if Sciex is dropped on this basis) the total sales in 1994 would rise to about $240M and total employees would be about 2,400.

We are presently investigating the genesis and size of these and other companies and would appreciate any input that readers may have. The companies involved are: Gennum (formerly Linear Technology), BOMEM, Develcon, Fibermetrics, Diagnospine, Nova Crystal, Profco., TRLabs, Sciencetech, Techware (now Brooks Automation), Datec Coating, Millenium Biologix, Corona Vacuum Coaters, Biomedical Photometrics, Electrophotonics, Exfo, and Resonance..

3.3 Second-Order Spin-Offs

It is well to recall again that the above analysis does not take into account the likelihood of second order spin-offs from the spin-off company itself. As mentioned previously, an informal study by the University of Saskatchewan Physics Department, for example, found [8] that just one of the companies contributing to Table 1 (SED) has spun-off approximately 20 additional companies in Saskatchewan.

3.4 The World-Wide Web

Finally, although Sub-Atomic Physics has no companies in the above analysis, it should be remembered that this subdiscipline can make an excellent case for recognizing an appropriate portion of the enormous revenues which now flow from the World Wide Web. This technology was not only invented at CERN, but was created precisely because of the widely and internationally cooperative nature of the Sub-Atomic discipline. The final report may attempt to roughly quantify this impact.

4. THE IMPACT OF TECHNOLOGY LICENSING

4.1 Introduction

Where a company is not spun-off directly by the owner of the technology, the corresponding intellectual property may be licensed to an existing or new company. This gives the company the exclusive or nonexclusive right to exploit the technology, often with specific limitations. Most commonly, the consideration for the license is a royalty equal to some percentage of the company's revenues from exploiting the technology. In some cases, the licensor may instead or in addition take an equity position in the licensee company.

The U.S.-based Association of University Technology Managers (AUTM) publishes royalty data for all member universities in the U.S. and Canada. The total royalties reported by AUTM [25] for Canadian universities for FY 1994 are C$7.6M, but no breakdown by discipline is reported, and according to AUTM [26] none is available here or in the U.S. The royalties are rising fairly fast, with the corresponding figures for 1991-93 being C$3.9M, $5.1M and $6.7M. It is important to remember that (unlike the NSERC spin-off data), the AUTM figure includes technologies associated with MRC researchers; again, no breakdown appears to be available. Also, Canadian licenses may be to foreign firms in some cases, in which case the benefit to Canada seems likely to approximate the license revenues received, rather than the associated company revenues.

4.2 General Magnitudes

It is instructive to compare in very broad terms the likely corporate incomes which give rise to the royalties reported by Canadian universities. To do this, one must make an assumption about the relation between the two, i.e. about the royalty rate. AUTM [25] reports, apparently with approval, a study carried out in the U.S. which assumed an average royalty rate of 2%. This is low in our own business experience, and indeed the average rate reported in our own study (section 4.3) is just over 4%. From a published TRIUMF report [5], we calculate their average royalty rate as just over 3%. With some universities, the matter is complicated by arrangements which may not always be simple percentage royalties, but to get a rough feel for revenues, we will assume a possible range of 2-4% for the royalty rate.

The company revenues associated with the 1994 Canadian royalties are thus estimated as $190-380M p.a., probably towards the bottom half of the range. For our purposes, this must be reduced by the revenues received by foreign companies. We know of little data on this point, but the average in our own study is about 20%. We emphasize, however, that this estimate is rough, and that the proportion varies drastically from university to university. We thus arrive at a very rough estimate of $150-300M for the associated Canadian corporate revenues, again probably towards the low end of the range. This figure relates to all disciplines, notably including the MRC-supported areas, and is to be compared with the $600M figure [18] for spin-off companies from the NSERC disciplines alone. This tends to support the view which is often expressed [27] that the impact of spin-off companies may be substantially greater than that of licenses.

4.3 Physics Revenues

With the kind help of Phil Gardner and Ann Fong of the TRIUMF Ventures Office, we have attempted to obtain the two key pieces of information needed to estimate, apparently for the first time, the impact of Canadian university physics licensing. These are the royalties associated with physics faculty members, and the average royalty rate. As mentioned above, we also asked questions to enable us to estimate the Canadian content of these revenues, as well as the likely incrementality of the revenues. In most cases, the incrementality was judged to be very high. Despite the involvement and persistence of the TRIUMF people, who are well known in their community, this data proved to be difficult to obtain, because of the unwillingness of many Technology Transfer Offices (TTOs) to cooperate. Eventually, however, we received replies from eight university TTOs representing 45% of the 1994 license revenues mentioned above. These replies reported $133,000 of royalties from physics-related inventions, although (judging from the general quality of some of the replies) we have serious doubts as to whether some respondents really attempted to trace the innovations to the originating discipline.

Taking the data at face value, however, and (i) applying the 80% Canadian estimate, (ii) assuming a 2-4% royalty rate, and (iii) uplifting the result by 100%/45%, we arrive at a very rough estimate of $6-12M p.a. for the Canadian corporate revenues from licensed physics technology. This does not include TRIUMF which, as we shall see, is more of a success story. This figure should be treated with great caution, given the obviously large uncertainties; however, since it will not form a large portion of the total estimated impact of physics, it is probably sufficiently accurate for our purposes.

As indicated before, we have no way of estimating how much of the total royalties reported by AUTM are from non-NSERC disciplines although, anecdotally, we hear that the proportion is high. Thus, we cannot compare physics with other disciplines, as was possible for spin-off companies.

Strictly speaking, our $6-12M p.a. estimate, like the spin-off estimates, should be corrected for discounting effects associated with the delay between research and revenues. However, for the present, we anticipate little correction to the spin-off company data from this source, and (particularly given the inexact nature of the licensing estimate) we suspect that no significant correction will be needed here either.

4.4 The Future

While the marginal quality of the data does not severely compromise the present study, because of the fairly low licensee revenues estimated for all disciplines, it is important to add that these impacts may well not stay negligible for long. The average license revenues reported by our respondents were four times those of the AUTM 1994 values. We are not at all sure that this represents reality. However, perhaps more significant is the very much higher revenues in the U.S., where licensing has probably been emphasized for longer. Total 1994 license revenues for U.S. universities, not including those received by patent management firms, were U.S.$266M, or about C$350M; this is to be compared with Canadian revenues of C$7.6M. The U.S. figure had doubled in the three preceding years. Even acknowledging that the ultimate U.S./Canada ratio may not be the traditional economic 10:1, this suggests that Canadian revenues could well rise quite rapidly in years to come and that economic activity associated with licenses could become a significant justification for NSERC expenditures. This leads to Recommendation 1:

> Recommendation 1. NSERC should take action to ensure that it receives reporting from universities on their licensing activity in sufficient detail for economic impacts to be estimated with reasonable confidence for the NSERC disciplines as a whole.

4.5 TRIUMF

Since the basic question in the present study is the extent to which NSERC support of physics is a necessary but not perhaps a sufficient condition for various impacts, a good case can be made that the economic impact of TRIUMF's licensing efforts should be included. After all, TRIUMF's main *raison d'etre* is to support academic research in various fields of physics, primarily Sub-Atomic. Moreover, the efforts of TRIUMF are, of course, carried out very much in conjunction with academic researchers.

How large is this impact? Phil Gardner and Ann Fong of the TRIUMF Ventures Office have kindly provided a list of conservative estimates, as of April, 1997, of the corporate revenues being received from technologies licensed by TRIUMF. These total just under $20M p.a., a figure which may be unusually low [28] because of a temporary dip in this income in the last year. Of this, a little over $15M p.a. is being generated by Canadian firms, and virtually all of this is believed [28] to be incremental to Canada. In addition [28], these licenses generate about $3M p.a. of TRIUMF development contracts and the like, much of it from outside Canada. Thus, we estimate a primary economic impact of about $18M p.a., or more than 50% of TRIUMF's budget! Even if we were to allocate this between NSERC physics and TRIUMF, based say on the relative annual spending, we would still estimate an impact of about $10M 'attributable' to NSERC physics.

5. MEDIUM-TERM IMPACT ON EXISTING COMPANIES OTHER THAN VIA LICENSING

5.1 Introduction

This impact really represents the intermediate case between (i) the kinds of impacts discussed above, which are moderately straightforward to estimate, at least in principle, and (ii) very long-term effects like the underpinnings of the computer revolution which, though enormous and critically important, are extremely difficult to estimate and to attribute to any one country. Such intermediate effects have been the topic of extensive work in the U.S. by Edwin Mansfield.

In a particularly well-known paper [10], Mansfield studied firms in seven industries: information processing, electrical equipment, chemicals, instruments, drugs, metals, and oil. He concluded that about 10% of their new products and processes introduced in 1975-85 could not have been developed (without substantial delay) in the absence of recent academic research. Another 7% or so were developed with 'very substantial aid from recent academic research'. 'Recent research' was defined as research occurring within 15 years of the commercialization of the innovation. The mean time lag between the last of the research results and commercialization was 7 years.

Taking these industries as a whole, new products first commercialized in only a four year period (1982-85) that could not have been developed without substantial delay in the absence of recent university research accounted for about $24B of sales in 1985 alone, and another $17B were developed with very substantial aid from recent academic research. These industries experienced a further $7B and $11B in savings due to new processes which could not have been developed without academic research or which needed very substantial aid from such research.

In 1995, Mansfield [29] reported that he was updating these findings to the 1986-94 period (replacing the oil industry with machinery) and was finding few significant changes, except that the time lag between research and commercialization might have decreased.

Based on data from the earlier paper, Mansfield [10] went on to estimate the rate of return from worldwide academic research in 1975-78 to be about 28%, if benefits to users were included (i.e. the social rate of return, section 1.2), and about 10% if these 'secondary' benefits are ignored. These estimates, as we have commented elsewhere, rest on some rather large assumptions, but they are the source of the 28% figure which is so widely quoted.

The above work does not distinguish between different academic disciplines. In later work [30], Mansfield attempted to obtain some information on this point by asking companies to name specific researchers who were important to them. Physics was represented amongst these, but the data given is insufficient to make even a rough quantitative estimate of the contribution of physics to the totals. Moreover, it is obvious, as has been pointed out elsewhere [2], that there will be a strong and natural tendency for respondents to recall more recent efforts (such as their own work, or downstream university contributions), so that the impact of more basic research in areas like physics is likely to be severely underestimated. As pointed out in reference 2, "*chemistry is not used just in the chemicals sector*" (where it received most if its citations in reference 30) "*but also in a large range of user industries, and other academic disciplines like physics and mathematics have still* *more pervasive impacts*."

Even the large impacts estimated by the above work are likely to underestimate the real situation, again perhaps because of lack of knowledge by respondents of the real source of advances. The 'Yale Survey' [31] of 650 U.S. industrial Research Directors found that the generic relevance of a discipline to industrial technologies was perceived to be much greater than that of specific university research results. Yet we would assume that a large proportion of those advances probably really arose in, or because of, academia! Interestingly, the importance of physics as a field was widely cited (by 44 industries), behind only materials science (of which physics is, of course, a major part) (99 citations), computer science (79), chemistry (74) and metallurgy (60). The authors comment that the failure to cite specific university results "*by no means implies that new findings in fundamental physics, for example are not relevant to industrial innovation. Rather,…. advances in fundamental scientific knowledge.. influence..industrial R&D largely through two routes. One..is through influencing the general understandings and techniques that industrial scientists and engineers…bring to their jobs. The other is through their incorporation in the applied sciences and engineering disciplines and their influence on research in those fields.*"

Effects of the kind considered in the present section are presumably largely responsible for findings like the recent estimate [32] that 73% of the main science papers cited by American industrial patents in two recent years were based on domestic and foreign research financed by government or nonprofit agencies.

5.2 Possible Impacts in Canada

It seems important to ask very roughly how large the effects of this kind might be in Canada across all disciplines, so as to compare this with better known impacts such as those discussed in the preceding sections. Recall that we are asking how much Canadian innovation might flow from Canadian research, as compared with U.S. innovation from U.S. research, i.e. we are not considering cross-terms like Canadian innovation from U.S. research and the converse. Amongst other factors, it seems clear that the impact could be proportional to the amount and quality of research done; perhaps we might roughly estimate this as say 5% of the U.S.[h] This might at first sight suggest a crudely 20:1 ratio between Canada and the U.S. for this impact. However, a case might be made that the impact could also be proportional to the receptor capacity of Canadian companies, which (if estimated by Canadian industrial R&D) would also be rather worse than one-tenth that of the U.S., say of order 5% again. If both factors were at work, this would increase the 20:1 guestimate above to of order 400:1. We suspect that the correct answer may be somewhere between the two, depending perhaps on whether matters are dominated by either 'technology push' or 'market pull', or by a combination. Mansfield [30] found that geographical proximity also played a role, but that it was far from the only factor.

The total U.S. impacts (in mid-1980's dollars) found by Mansfield and listed above are in the region of U.S.$60B, or C$80B. Recall again that this applies only to products introduced in 1982-85 and only to seven industries; as discussed above, it is also likely to be an underestimate. Even with these limitations, and using the range of Canadian possibilities discussed above, we can speculate that the possible impact for all NSERC disciplines (which would have been the key ones of importance in Mansfield's work) could be of the order of $200M-$4B! [i] This is to be compared to the $600M of revenues estimated by NSERC in 1995 [18] for spin-off companies from all NSERC disciplines.

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[h] This guess (one-half of the general population ratio) seems accurate enough for our present order of magnitude purposes. Work for the present Review of Physics, for example, found [33] that roughly 3% of papers in Phys. Rev. B, which of course carries papers from around the world, originated in Canada.

[i] Since many of the advances considered by Mansfield were fairly routine, it is not entirely clear that our normal high-tech 'incremental to Canada' assumption would apply fully here.

We make no claims except one for the above estimate, which is clearly massively crude. The one claim is that this infrequently discussed economic impact of NSERC research could be extremely significant. This is consistent with the view, which is gaining acceptance [4], that much or even most industrial innovation occurs in rather indirect ways, rather than via a direct application of recent research results. This leads to our next recommendation.

> Recommendation 2. NSERC should initiate a major study of Mansfield-type effects in Canada, in sufficient detail for their economic impacts to be roughly estimated for the NSERC disciplines as a whole. This could go a considerable distance towards removing the underestimating which is implicit in considering only direct impacts such as spin-off companies.

5.3 Our Study

Since there is little data on physics in Mansfield's work, and since no Canadian data of any kind seems to be available, we attempted to perform a much simplified version of Mansfield's studies here in Canada, by approaching[j] a subset of the top 50 R&D-performing companies in Canada and asking them for similar data about physics. We find that companies are sympathetic, but do not know how to break-out in a simple way the impact of university research generally, or the physics impact from that of other disciplines. In fact, Mansfield probably had the same issue, for the reasons discussed above, and he indicates that he had to work extensively with the companies which he studied, after approaching them at the level of the Chairman of the Board.

As a result, we reluctantly concluded that this type of investigation is well beyond the means of a study such as this. As recommended above, we believe that NSERC should look into the matter in much more detail. It should not be forgotten, however, that much academic work is almost certainly transferred via graduate students. As a result, the rough calculation in section 6 of the economic value of graduate student training will perhaps cover the above effects to a small extent.

Despite the difficulties with the study, one rather clear outcome was the remarkable proportion of the respondents who said, without being prompted, that the key (and important) outcome of university work from their standpoint is the availability of trained graduates. This leads naturally onto our next impact.

6. THE ECONOMIC IMPACT OF GRADUATE STUDENT TRAINING

6.1 Introduction

Despite the great interest in estimating the economic impact of scientific research, little or no effort seems to have been made to estimate the parallel economic impact of graduate student training, either in Canada or elsewhere, nor to compare it with government support of research or with other impacts. Reference 4, for example, comments that "*While it is easy to measure inputs and outputs (e.g. number of students entering and graduating, respectively), measuring the* <u>*impacts*</u> *of training is almost never done*". As we shall see, it is probably a substantial impact. Estimating it may add a significant additional quantitative economic argument for NSERC research. Indeed, there is a growing realization ([2] and references therein) that the transfer of capabilities, modes of thought, and knowledge to the 'outside' world via people may be at least as important as the direct transfer of information by more formal routes, and that this value may have little directly to do with the specific discoveries of the field in which the people previously worked.

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[j] This work was carried out by James Farley and Beverly Robertson of the University of Regina.

Our approach to estimating this impact is somewhat similar to that used to estimate the value of undergraduate education in some earlier reports ([34] for example), although we are not convinced that a proper 'apples-to-apples' comparison with the associated government expenses is always made by these studies.

In common with earlier estimates [34] of the value of an undergraduate degree, the basis for our impact estimate is the assumption that employment markets pay roughly for value received. Thus, the first steps are to estimate the lifetime difference between the average earnings of (i) an M.Sc. or a Ph.D., and (ii) a B.Sc., to discount these amounts to present values (section 1.5), and to multiply the results by the number of people involved. In our case, we then allow roughly for emigration and try to fit the result into our primary economic impact model.

This approach, of course, assumes that the reason for the increased earnings is almost entirely the additional education. Studies considering undergraduate education [34] sometimes correct the additional earnings by about 20-30% to allow for the higher native ability of university graduates, even before they attend university. We suspect that this effect would be considerably smaller in going from B.Sc.'s to M.Sc.'s and Ph.D.'s, and for our present rather rough calculations we have ignored it. We shall also consider all graduate students in physics, even though some, of course, are supervised by non-NSERC grantholders. The purpose of this study is to estimate the economic impacts for which NSERC Research Grants are a necessary condition; given the importance of a critical mass in any given department, we doubt that many graduate students would be trained if such grants did not exist.

The approach also assumes that unemployment is low amongst Ph.D.'s and M.Sc.'s. Judging from the HQP part of the present Review of Physics, and from earlier NSERC data, this is a very good assumption.

6.2 Salary Differences between B.Sc.'s, M.Sc.'s and Ph.D.'s

A review of CAP's 1995 salary survey [35] suggests immediately that higher salaries may indeed be associated with higher degrees. Excluding age ranges where B.Sc.'s may well still be graduate students, and adjusting for differences in the ages of the respondents, one would calculate a difference of about <u>$18K</u> per year between Ph.D.'s and B.Sc.'s. However, this must be viewed with the greatest caution, since the number of B.Sc. respondents is very low, likely reflecting CAP's membership profile.

The number of Ph.D. respondents to the CAP survey, however, is fairly large (255 people in 1995), and the median salary is $74K for 1995, and $75K in 1993 [36] and 1994 [37]. Statistics Canada [38] shows an average salary, based on a 20% sample, for the 'Physicist' category (category 2113) of $51.2K. This is in 1990 dollars and apparently for the 1991 year. If we uplift this by the 5.6% inflation rate for 1991 and at say 2-3% p.a. thereafter, we arrive at estimates of $56-57K for 1993, $57-59K for 1994, and $59-61K for 1995. Since all teaching occupations (including university teachers) are in other Statscan categories, one would assume that the Physicist category would contain at least a fairly large proportion (but not 100%) of non-Ph.D.'s. Thus, the difference of <u>$13-18K</u> might be argued to be an underestimate of the real difference.[k] On the other hand, it is also possible that there could be some downward bias in the Physicist number, and thus an upward bias in the difference estimate, because of people leaving physics later in their careers, perhaps

[k] There is a separate category for Physical Science Technologists and Technicians, so the 'Physicist' number does not seem likely to be significantly diluted by non-degree people reporting themselves as physicists.

for higher paying jobs outside of the scientific world.[l]

There is additional Statscan data [39] on a specific sample group of individuals who graduated in 1986. For Mathematicians and Physical Scientists as a whole (no finer breakdown was given), this shows a roughly $10K difference between B.Sc.'s and Ph.D.'s, and $5K between B.Sc.'s and M.Sc.'s., in both cases with the higher degree having the higher earnings.

A final piece of circumstantial evidence for a real difference between Ph.D. and B.Sc. salaries comes from other Statscan data [38] on 1991 earnings, specifically the difference between the earnings of university teachers and secondary school teachers. This seems like a reasonable surrogate comparison, since the main difference between the two jobs is probably the research aspect, for which the Ph.D. is needed; both groups are national, unionized, and in the teaching business. The difference in salaries shown by Statscan is $17K, which if uplifted to 1995 at a conservative 1.5% p.a. would be over $18K.[m]

While the above data is highly suggestive of a difference between B.Sc. and Ph.D. salaries in the range of $10-20K p.a., it would be more satisfying to have more controlled and detailed data. The above data has therefore been supplemented by extensive Chemical Institute of Canada (CIC) information on chemists [40] kindly provided by Ann Alper, Executive Director of CIC. We strongly suspect that these will be a reasonably accurate surrogate for physicists. We have analyzed the 1993, 1994 and 1995 CIC data (the last being the most recent available at the time) by age range and degree, and obtain the following results for 1995 as an example. Although it would not have affected the final numbers greatly, we did not use the first range in the CIC data (those obtaining their bachelors degree before 1956) or the last (post 1990 graduates); the number of respondents in the first range was much too small to allow reasonable comparisons between degree types, and the last is inappropriate, since many of the B.Sc.'s would still be in graduate school and the graduate degree population is therefore small. The first number in each of the total salary columns below is the average salary, and the second number (in brackets) is the number of respondents in that category.

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[l] The effect of movement into technical management does not seem likely to be large. The average Statscan salary for its separate category (#1131) of Management Occupations in Natural Science, Engineering and Mathematics (NSE) is only $12K higher than that for Physicists [38], and the numbers of individuals is only 4% of total NSE occupations.

[m] There is the possibility of bias in these numbers related to differing degrees of gender equality in Secondary School and University teaching, and also related to possible regional effects (conceivably, there could be proportionately more universities in higher-income regions than there are schools). In fact, comparing men only leads to a difference of $18K instead of $17K (1990 dollars) while comparing for both genders but in only e.g. Ontario leads to a difference of $16K. Within the overall accuracy of the discussion, these effects are not material.

Table 2. Salaries Extracted from 1995 CIC Salary Survey

Year of B.Sc. Graduation	Annual B.Sc. Salary ($K) and (# of people)	Annual M.Sc. Salary ($K) and (# of people	Annual Ph.D. Salary ($K) and (# of people	Difference ($K): M.Sc. – B. Sc.	Difference ($K): Ph.D. – B. Sc.
1956-60	75.2 (22)	79.7 (8)	85.9 (85)	4.5	10.7
1961-65	72.6 (27)	86.5 (9)	86.3 (115)	13.9	13.7
1966-70	72.6 (38)	74.6(24)	80.6 (95)	2.0	7.9
1971-75	71.9 (40)	69.0(15)	75.4 (60)	(2.9)	3.6
1976-80	58.8 (49)	82.8(20)	67.6 (57)	23.9	8.7
1981-85	56.9 (30)	56.8 (20)	58.6 (58)	(0.1)	1.7
1986-90	52.7 (27)	45.7 (12)	52.3 (53)	(7.0)	(0.4)
Average	65.5 (233)	70.2 (108)	75.4 (523)	4.7	9.9

We note the following about Table 2:

(i) The average salary for Ph.D.'s ($75.4K) is similar to CAP's median of $74-75K. In fact, if one allows for the slightly different age distribution in the two surveys and for CAP's use of median salaries rather than CIC's average, the difference appears to be well under $1K. This encourages us in our belief that the two disciplines are comparable.

(ii) The average B.Sc. salary is $4-6K higher than the Statscan data for 'physicists' generally. If we use all age ranges (as the Statscan data would have done), the difference is unchanged. However, for the 1993 and 1994 CIC data (which we shall use later) the difference is only $2-3K. These differences are small enough that again we are encouraged to think that the CIC data is a good surrogate. We suspect that the remaining difference could reflect the presence of about 18% of engineers in the CIC data; while Ph.D. salaries (which are significantly weighted by unionized teaching positions) might reasonably be expected to be comparable between scientists and engineers, we suspect that bachelors' salaries might well be a little higher for engineers. As a result, our use of the 1993-95 CIC numbers in our subsequent calculations appears conservative.

(iii) The CIC data shows a negative difference for M.Sc.'s for the 1986-90 cohort and a slightly negative one for Ph.D.'s. This echoes the finding of the HQP study of the present Review of Physics; for about the same age range, this found a slightly negative Ph.D. difference (although this actually largely disappears if one compares comparable jobs and degrees). The reason for these effects, no doubt, is that both surveys compare people with the same years from B.Sc. Given that salaries tend to advance fairly rapidly after a person becomes 'gainfully employed', one would expect that B.Sc.'s would have a small advantage in this age period, which would temporarily tend to offset the advantage of a graduate degree.

To minimize random salary variations, which cause considerable year-to-year fluctuations, particularly in the (M.Sc.-B.Sc.) data, we averaged the data from all three CIC studies. In fact, the 1993 and 1994 data show substantially fewer fluctuations than 1995. For 1993-95, the average (M.Sc.-B.Sc.) salary difference is $4.7K, $5.3K and (as shown above) $4.7K p.a.; uplifting all these by say 2.5% per year for intervening salary increases, we end-up with an average 1997 estimate of $5.2K. For Ph.D.'s, the differences are $11.1K, 12.5K and $9.9K, for an uplifted 1997 average of $12.0K.

In summary then, we conclude on the basis of the CIC data that the salary difference between Ph.D. and B.Sc. physicists, while low or even negative for the first few years (a conclusion shared by our own HQP data), probably goes on to average about $12K p.a. over a career. The difference for M.Sc. people appears to be roughly $5K. Remembering that most of the other estimates in this section gave higher values for these differences, the use of the CIC figures seems conservative.

6.3 Discounted Value of a Career's Earnings

In order to estimate the value which a faculty member creates when a Ph.D. or M.Sc. is graduated, we need to sum the annual salary differences estimated above, with due regard to the time value of money. This is done (section 1.5) by discounting income received in the future by a discount rate, compounded over the number of years involved.

One question is whether the lower income received by a graduate student during his/her studies should be factored in. While this would be appropriate for an individual's own calculations, we do not believe it should be done when calculating values to the economy. This is because we do not believe that a graduate's student's value to the economy during his/her research is less than that of a person of similar age who is gainfully employed as a scientist: comparable research is being done and there is no evidence that this is of less value than work done say in industry. The graduate student is simply paid less, for reasons having to do with availability of money in a basically monopolistic situation, rather than economic worth.

We therefore performed the discount calculation by summing the differences for each year covered in Table 2 and its 1993 and 1994 analogs, and discounting at a rate equal to the inflation rate plus 3% (section 1.5). As to inflation, the numbers in Table 2 are a snapshot and will presumably increase over time at least roughly in step with inflation. Conservatively, therefore, the inflation rate cancels out and the net discount rate applied is 3%. This calculation also automatically takes account of another correction: the averages of the CIC numbers are naturally weighted by the numbers of individuals in each age range, i.e. the average is the total earnings divided by the number of people. In the present calculation, we must obviously weight each age range equally (ignoring mortality effects). We did not use CIC's earliest time period in section 6.2 (B.Sc. earlier than 1956), since the numbers reporting in all categories were small. This cuts off the comparison when people are roughly 60, and so this may also crudely account for mortality effects.

The non-discounted value of the career difference in earnings then comes out to be about $260K for a Ph.D. and $120K for an M.Sc., while the discounted numbers are $135K and $65K respectively.

6.4 Ph.D. and M.Sc. Generation

A study published by CAP in 1995 [41] reported that about 150 Physics Ph.D.'s and about 275 M.Sc.'s graduated from Canadian universities in each of the years 1992-94, numbers which had shown a steady increase from about 100 and 160 respectively in the mid-1980's. Ph.D.'s, at least, were still on a strongly rising trend at that time, but we will conservatively assume that the numbers are roughly unchanged today. This is supported by the latest detailed listing [42] of physics Ph.D.'s granted in the preceding year; this lists 136 people; since full details were required for inclusion in this list, we would expect it to omit a few people. This list [49] showed 150 people in 1995. In 1992-94 it showed 101-128 (compared with about 150 in reference 41), confirming that it tends to underestimate somewhat.

However, in order not to double-count, we must subtract from the M.Sc. numbers those who go on to become Ph.D.'s. We are told [43] that this is likely 80-85% of the numbers of Ph.D.'s. We therefore subtract 125 from the M.Sc. numbers to arrive at an estimate of those who stop at that level. We end-up with 150 Ph.D.'s per year and, quite coincidentally, 150 M.Sc.'s.

Since we are calculating incremental value to Canada from later employment here, we must also subtract from these numbers the proportion who are international students and return to their homeland after graduation. We must also subtract the proportion of Canadians who emigrate after graduation. We are presently still gathering data on these proportions. For the present, the following analysis should show the broad principles. For Natural Science and Engineering generally, NSERC figures [23] show that approximately 20-30% of M.Sc. students are international. For Ph.D. students, this rises to about 35-40%. Reference 41 indicates that 15-20% of all physics graduate students were Visa students in 1992-94. The 'export' created by the universities in teaching these people will be considered in section 7, but for the present we conservatively subtract the NSERC percentages from the above figures. For the present, we also assume that subsequent emigration is roughly offset by the number of foreign students (a high proportion of whom apparently come here with permanent resident status) who stay here after graduation. This is roughly consonant with the proportion of all gainfully employed Ph.D.'s in our HQP Study who did Canadian Ph.D.'s and remained here (about 70%). Better numbers are being sought for these percentages, and readers' input is solicited.

For the purposes of this section, we thus end-up with about 95 Ph.D.'s who stay, and about 110 M.Sc.'s.[n] Simply multiplying these numbers by the dollar estimates in the previous section gives $12.8M p.a. for Ph.D.'s and $7.2M for M.Sc.'s, for a total of $20M. This does not appear to be the end of the story, however.

6.5 Calculation of Actual Impact

Calculations of this kind have been made for undergraduates in several other studies [34]). These calculate the discounted value of the additional earnings stream and consider this (net of costs) to be the economic benefit. While this may be appropriate for the U.S. situation (a rather self-contained economy), we suspect that it may be very conservative for Canada. Consider, for example, a company hiring a Ph.D. instead of a B.Sc. At the very least, the company must expect that it will maintain or slightly increase its profit by doing so. But its profits, even on an incremental basis, are not equal to 100% of the associated revenues! Indeed, even incremental profits would rarely exceed 25-30%. Thus, in order to pay out $X in additional salary to a Ph.D. (instead of a B.Sc.), the company must expect that its revenues will increase by at least $4X.[o] But, by the assumptions we have used all along, this (generally high-tech.) company will be selling into an international market and, as explained in section 1.1, revenues created by such high-tech advances are essentially incremental to Canada. Moreover, it is these revenues, not incremental profits, which we argued is the proper measure in comparing impacts against government expenditures. Recall, once more, that this might well not be true in the U.S.

What we have, then, is a multiplier of order 4 to be applied to the figures in section 6.3 in order to arrive at the primary economic impact, at least for graduates going into industry. (It is important to understand that this multiplier has nothing whatever to do with the 'consumer' multipliers discussed in section 1.1, which measure the extent to which corporate revenues circulate more than once in the economy as their recipients spend the revenues.)

It is harder to determine an appropriate multiplier, if any, for people entering other sectors. First, however, who goes where? The HQP Study of the Review of Physics indicates that of those (fairly recent) Ph.D.

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[n] There is a rather subtle question as to whether each faculty members' training of his/her own replacement (i.e. one graduate student per career) should be subtracted from these numbers, since many of that person's economic contributions would eventually be counted under the other impacts in this study. However, even if such a correction should be made (which is not clear to us) this would be at most a roughly 10% correction to our final numbers. Given the overall accuracy of these estimates, it seems reasonable to neglect this questionable correction.

[o] The effect may be delayed, of course, perhaps by many years. But on a discounted cash flow basis, the company cannot be acting in its economic interests unless it believes that this statement is true.

graduates who are now 'gainfully employed' in Canada (in principle not including post-docs) approximately 30% are in industry, 51% in education, 15% in government, and 4% in 'other'. For M.Sc.'s gainfully employed in Canada, the numbers are 43%, 29%, 16%, and 12%. Of those in education, only 10% of M.Sc.'s and 15% of Ph.D.'s indicated that their job classification was research (rather than teaching), so apparently these people are not dominated by R.A's and the like. It also seems unlikely that most are in university faculty positions, since we estimate[p] a total of 750-850 university physics faculty positions in Canada; thus, at least in the steady state, only about 800 people/(30-35years) or roughly 25 faculty positions would become vacant per year. This is only about 25% of the roughly 95 Ph.D.'s who graduate and eventually stay here per year, and not all of these positions are filled by Canadians. We must assume, therefore, that most of the other educational people, especially the M.Sc.'s, are in non-university (presumably post-secondary) institutions.

A case could probably be made that there is a multiplier for people in teaching institutions. Presumably, at least in non-university situations, if all faculty were less qualified (and lower-paid), this would be reflected primarily in lower fees. If the students (and society) are acting in their economic interest in paying the fees, they must expect that they will be recompensed by higher earnings later (presumably in industry primarily), and indeed studies (at least for universities) [34] bear this out strongly. Thus, the incremental faculty earnings associated with their higher degrees could be argued to reflect their graduates' expected incremental earnings rather than the associated incremental corporate revenues, which will be much higher. We appreciate, however, that this is a long argument with many uncertainties. The situation seems less clear still for government employees. Given the uncertainties, we have applied a 3.3x multiplier to the graduates working in industry, corresponding to a high, and thus from our standpoint conservative, corporate incremental profit margin of 30%. For the other people, we apply either no multiplier (i.e. 1x) or one half of the additional amount used for industry (i.e. 2.15x)[q]. This will give us a range of estimates.[r]

<u>The result so obtained is a total value of $14.5-19M for M.Sc.'s and $21-31M for Ph.D.'s, or in round terms a grand total of just over $35-50M</u>. In addition, the following section will estimate an impact of about $5M for the Canadian spending by graduate students trained here who do <u>not</u> remain in Canada. While this is easier to discuss in the following section, it seems logical to add it to the above total, for <u>a final estimate of $40-55M.</u>[s]

The uncertainties in the above calculation hardly need emphasizing. However, the calculation is sufficient to indicate fairly clearly that this impact is substantial. Again, a proper NSERC study on this point for the NSERC disciplines as a whole would seem to be of considerable importance and could significantly help

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[p] This is based on a count of physics faculty (excluding emeriti, adjuncts and most astronomy faculty) on the Web pages of all the universities in three Provinces (Ontario, B.C. and Saskatchewan), chosen to be representative of large, medium and small Provinces (by population). The numbers so obtained were grossed up to the whole of Canada using the ratios of (a) population and (b) all university degrees granted; the difference between the two calculations gives the range shown. The calculation may, of course, be somewhat high for Quebec, because of the CEGEP system, but is probably sufficiently accurate for our purposes.

[q] Obtained by subtracting the undoubted 1x from 3.3x to yield the incremental 2.3x, dividing by two and adding back to the 1x

[r] Since we will be weighting industrial Ph.D.'s more heavily than the average, it could be asked whether their salaries are properly reflected in the CIC Ph.D. data, in which academics will be heavily represented. In fact, industrial salaries are believed [44] to be significantly higher than those for academics (about $10K near the start of careers), at least for chemists. We see no reason to believe that physicists will be drastically different, so our approach is probably conservative.

[s] Of course, general Provincial government university spending (estimated [34] at about $82K per degree at U.B.C.) plays a major role in the generation of post-graduate, as well as bachelors, degrees. The objective of this study, however, is to estimate the impacts for which NSERC Research Grants are a necessary, but not always a sufficient, condition. Also, if we were to compare the impacts in this study against NSERC grants <u>plus</u> the universities' infrastructure spending on physics research (likely, section 1.6, of order $35M per year), then much of the incremental cost of physics graduate degrees would already be counted: 425 degrees/year x $82K is, in fact, about $35M.

justifications for increased NSERC spending.

> Recommendation 3. NSERC should initiate a proper study of the economic value of graduate student training for the NSERC disciplines as a whole.

7. THE ECONOMIC IMPACT OF THE TEACHING OF INTERNATIONAL STUDENTS

Canadian universities are rightly regarded as excellent on an international scale, and as a result they attract a large number of international students, particularly at the graduate level. These students not only pay full tuition fees, but also live and spend in Canada for the duration of their stay. In most cases, especially with Visa students, it seems reasonable to assume that the money for these activities comes largely from overseas. The universities involved thus provide a service and Canada receives foreign money as a result. That is, the universities act as exporters of a service.

While NSERC is far from the only financial supporter of university science research, we have previously argued that it seems highly unlikely that a significant research effort would survive if all NSERC support disappeared. That is, NSERC appears to be a necessary (but not sufficient) condition for Canadian university science research to exist.

If NSERC support did not exist and neither did university science research, then it seems very likely that:

(i) very few international science graduate students would come to Canada,

(ii) the prestige of Canadian universities, at least in the sciences, would drop sufficiently that the number of foreign undergraduate science students would drop drastically, say by at least half,

(iii) more Canadians would go to foreign universities for undergraduate science studies, and

(iv) virtually no Canadian would do science Ph.D.'s or M.Sc.'s here.

The last effect should not be counted here, since the value of the present graduate training is covered by section 6. Effects (i) and (ii) would remove existing exports, and effect (iii) would cause an import which does not now exist. Put another way, NSERC presently causes import substitution in effect (iii). We now attempt to estimate roughly the impact of these effects.

According to NSERC [23], roughly 6% of Natural Science and Engineering undergraduate enrollment is international students. (For Canadian university undergraduates generally, AUCC [39] estimates about 5.6% of all undergraduates in Canada are 'international permanent residents' and 2.5% are Visa students.) We make the following assumptions: (a) the NSERC percentage is about right for physics, (b) there are about 13 undergraduates for each faculty member, based on the all-discipline number in reference 39[t], (c) we consider all physics faculty (about 800, see section 6.5), (d) the total spending by an international student is probably about $20K per year, including tuition, of which we assume that at least $15K comes from foreign sources. The total export is then the product of these four factors, or about $10M p.a.

To estimate the import substitution (effect (iii) above), we assume conservatively that say 5% more Canadian undergraduates would go abroad (more probably 10% for their last two years) if the reputation of Canadian universities dropped substantially as a result of a cessation of research. This would result in at least a similar per-student amount being spent abroad, for a total of $10M p.a. lost to Canada. Note that this does not take into account the value presently received by those Canadian undergraduates who would nonetheless

[t] We also found science-faculty numbers averaging in the same region at three university web sites.

stay in these dire circumstances; this is correct, since this by definition does not depend on NSERC research.

As to the export associated with international graduate students, whom we excluded from section 6, we consider the people who were excluded (55 Ph.D.'s and 40 M.Sc.'s) and multiply by the total amounts spent in Canada and originating elsewhere during the course in question. Rather than estimating the average number of years for a degree, so as to arrive at the total number of students at any one time, we can use actual numbers of physics M.Sc. and Ph.D. students reported [41] for 1993-94. These numbers (780 and 967), of course, will include those who may not ever graduate, which is correct for the present calculation. They also accord with our own estimate of roughly 2 graduate students per faculty member, based on numbers reported at the Web sites of various physics departments. Multiplying by the international percentages assumed in section 6.4 yields about 525 international students in total. We might assume that the total amount spent, including tuition, is about $20K p.a., but this needs to be reduced by perhaps 50% to allow for Canadian sources of income (scholarships, teaching, payments from the supervisor's Research Grants, etc.). This leaves a net 'export' of about 525 x $10K, or about $5M. This amount has already been added to the estimates in section 6.

Clearly, the above estimates, particularly the import substitution calculation, are especially rough. Again, however, the analysis seems to show that the impact could be substantial, and again it seems important to quantify it much better.

Recommendation 4. NSERC should initiate a proper study of the economic value of foreign student training for the NSERC disciplines as a whole.

8. OTHER IMPACTS

There are a few other impacts which might be considered.

8.1 Impacts on NCE's, Research Partnerships, etc.

Many researchers who are, or have been, primarily supported by the NSERC Research Grants program are also involved in the Networks of Centres of Excellence programs, other NSERC Research Partnership programs, or Provincial targeted programs such as OLLRC, etc. Since it seems improbable that most university researchers would be in a position to undertake efforts of this kind without earlier or concurrent Research Grant funding, a case could be made that any economic impacts from these programs is an impact of the Research Grants program.

We have not considered these impacts in any detail, for three reasons. First, we assume that they will be carefully studied by the programs involved and will (reasonably) be attributed primarily to programs other than Research Grants; it thus seemed more worthwhile to concentrate our limited resources on the impacts which are more specifically related to Research Grants. Second, and more practically, our brief investigations suggest that rather little is known about the quantitative impact of these programs. Some work has been done ([45], for example). However, we understand [46] that such investigations are so difficult that there is a tendency to back off from them at present. Third, one might expect great difficulty in separating out the contributions of the different disciplines in NCEs and the like.

As one specific way to try to estimate part of the impact of Research Partnerships, we contacted most of the individuals on a fairly comprehensive list [48] of physics researchers who have been involved in University-Industry awards which were initially approved in the years 1988-94. We asked them for specific examples of commercialized work, together with quantitative data. Unfortunately, we were able to obtain very little information[u], and again must suspect that little quantitative study has been done.

8.2 Non-Government Research Contracts

Many researchers who are supported, often primarily, by NSERC Research Grants also obtain research contracts from non-government sources, such as industrial companies. If these are from non-Canadian companies, the associated revenue (which is spent primarily in Canada) is clearly an export of services by the researcher concerned. If the support is from a Canadian company, it is possible that it would otherwise have gone to a foreign researcher. To the extent that this is true, the existence of the Canadian researcher replaces what would otherwise have been an import. We are presently attempting to obtain data with which to estimate this impact.

8.3 International Conferences in Canada

As pointed out by the TRIUMF Ventures Office [5], forefront research in Canada is a pre-requisite for the holding of international conferences here, and these conferences generate significant revenue.[v] We are presently attempting to make a rough estimate of these impacts.

8.4 Faculty Consulting

A study of the economic benefits accruing from the University of Calgary [47] had difficulty estimating the impact of faculty consulting, even for one university. In the end, it concluded that consulting created roughly half as many jobs as spin-offs. On the other hand, the consulting income reported to the annual CAP salary survey [35-37] is rather small (a median of $7.6K each for 26 people in 1995 for example, and comparable amounts in 1993 and 1994), i.e. probably about $200K or so in total. Unless the benefits-to-costs ratio of consulting is truly spectacular, it is therefore hard to believe that the Calgary numbers are applicable. We therefore neglect the impact of faculty consulting, although it would be valuable (but fairly time-consuming) to follow-up some specific examples on a case-study basis.

9. CONCLUSIONS

We have attempted to give a first, rough but conservative, estimate of some short- to medium-term primary economic activities which would not occur without the $35M p.a. NSERC physics Research Grants program. It appears that this can be directly compared with government expenditures, such as NSERC grants, in the sense that these estimates (shown in Table 3) represent the additional government expenditures which would be necessary to generate a similar economic impact in more conventional ways. Since these impacts give rise to consumer multiplier effects, similar to (but probably somewhat larger than) the multipliers which would occur if the government generated this activity directly, the total economic impact is probably 3 to 5 times higher than the numbers shown.

Table 3. Summary of Primary Economic Activity Estimates *

[u] However, we would like to acknowledge Bret Heinrich of SFU, who (with CTF Systems) went to considerable trouble to provide some data. Unfortunately, in the absence of more responses, it is very hard to use this; however, CTF's revenues are included in the Spin-Off company data in section 3. We also thank Jeff Dahn of Dalhousie for his helpful input on Moli Energy. Again, Moli is included in section 3.

[v] We do not believe that the converse, attendance at foreign conferences by Canadians, is usually an offset to this, since it is very often supported by NSERC, which is the expenditure with which we are making comparisons. More extended stays by foreigners in Canada or vice versa, however, are typically not paid for by NSERC, and so we would assume that these impacts roughly cancel each other out.

Impact	Primary Economic Activity Generated p.a. **Does <u>not</u> include consumer multiplier effects****	Comments
Activity directly generated by initial expenditure	$35M	Initial expenditure creates at least as much direct Canadian economic activity as most other government expenditures of this size.
Spin-Off Companies	> $130M	The origin of some other companies is still being investigated. Does not include the WWW , which spun-off from international sub-atomic physics.
Technology Licensing	$6-12M plus $10-20M from TRIUMF	TRIUMF total is about $20M, of which $10M might be allocated to NSERC based on relative expenditures.
Medium-Term Impacts on Existing Companies ("Mansfield" effects)	?	Probably large. Needs a major NSERC study.
Economic Present-Value of Post-Graduate Training	$40-55M	Includes Canadian expenditures by international graduate students.
Activity Generated by International Undergraduates Taught	$20M	Very approximate. Includes Canadian undergraduates who might otherwise go abroad. Does <u>not</u> include value received by other Canadian undergraduates.
Value of Non-NSERC Grants which Depend on Underlying NSERC-Supported Research	?	Information gathering underway
Amounts Spent by International Conference Attendees	?	Information gathering underway
TOTAL (excl. unknown amounts)	**$241-272M**	

* **Does not include long-term impacts of international physics, second order impacts e.g. second-level spin-off companies or other 'social returns', the value of faculty consulting, the impact of the World Wide Web, or the impact of the Research Grants program on researcher's ability to undertake collaborative efforts such as Research Partnerships, NCE's etc.**

** **These probably increase the numbers shown by a factor of 3 to 5**

In the one case where the data allows a reasonably reliable comparison between physics and other disciplines, General / Condensed Matter and Space Physics have far more than their 'share' of spin-off company revenues, despite their basic and long-term nature. They receive about 6.1% and 0.5% respectively of the total NSERC Research Grants budget, but account for 12.5% and 5.7% of all disciplines' spin-off revenues. Physics' revenues as a whole are 25% higher than its share of the Research Grants.

We emphasize again that Table 3 does not include a number of very important impacts.

- <u>The very large impacts of international physics on major inventions like the transistor, the laser, NMR, the World Wide Web, etc</u>. It could be argued that these are not incremental effects of NSERC work, because <u>to some extent</u>, Canada would share in the outcomes of these innovations anyway. In reality, of course, it is critically important that Canada be involved in these longer-term advances in order to recognize them early and to have the expertise to allow us to take full advantage of them. To quantify this is very difficult, although it would be interesting to study per capita revenues here and in the U.S. for major technologies where Canada has been heavily involved in the research stages, compared with those where our involvement has been less significant.

- <u>'Second-order' impacts</u>. One example is the so-called 'social return.' This has nothing to do with consumer multiplier effects but refers to the conclusion of many studies that the impact of an innovation on primary economic activity is far higher than the impact on the innovating company, because the improved products and processes reduce the costs to consumers and improve the economic performance of companies which purchase products from the innovator. This, of course, is an excellent reason why governments, and not just corporations, should support R&D. It may not be appropriate to consider most of these effects in a review of the <u>Canadian</u> impacts of <u>Canadian</u> research, since (given the international markets of high-tech companies) most of them would presumably accrue to non-Canadian companies; meanwhile, the Canadian impact of non-Canadian innovations is not a direct result of NSERC.

- <u>Second-level Spin-Off Companies</u> This is another second-order impact which should, in principle, be included but which is in practice difficult to estimate. It refers to companies which spin-off, not from a university directly, but from the original spin-off company itself, or perhaps even from a second-level spin-off. An informal study by the University of Saskatchewan Physics Department, for example, found that one of the companies in our spin-off study has spawned approximately 20 additional companies in Saskatchewan.

- <u>Mansfield Effects</u>. We have not been able to estimate the impacts, other than licensing, on existing companies, because of attribution difficulties which have plagued even extensive studies on these matters in the U.S. by Mansfield. However, we have given arguments to suggest that these effects could be very large and that they should be properly studied by NSERC.

- <u>Research Partnerships, NCE's, Targeted Provincial Programs, etc</u>. It seems likely that few researchers would be able to take part in such programs without concurrent or previous NSERC Research Grants. We have not estimated this impact, partly because there seems to be little quantitative data available. Nor have we estimated the impacts of faculty consulting.

Despite their limitations, the numbers imply that NSERC's investment in physics causes short- and medium-term economic impacts with present values far in excess of the associated investment. Other medium- and long-term benefits, which we cannot quantify, can be regarded as a very large "free" bonus on top of what is, even without such benefits, clearly an outstanding investment.

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