Review of Canadian Academic Physics

ECONOMIC IMPACT STUDY

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

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EXECUTIVE SUMMARY

The Economic Impact Study attempts to quantify, as far as possible, a range of direct Canadian economic impacts which would not occur without NSERC support of physics via the Research Grants program. Such a focus has obvious policy significance, but it constrains us to ignore the more indirect and long-term impacts of physics, even though they are very large. These typically depend upon a multitude of researchers from many countries, making their attribution to any one national effort almost impossible. Examples of such long-term physics-based impacts include many 'platform' technologies like the transistor or the laser, and major instrumentation and methodology advances such as NMR, magnetic resonance imaging, ion implantation or the World Wide Web. Despite the omission of such enormous advances, it is of great importance to establish whether, even without them, the short- to medium-term Canadian impact of Canadian physics is still large. The study concludes that it is very large. 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 value 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.

Detailed arguments are presented to suggest that the NSERC physics Research Grants effort (which accounts for about $36M of NSERC's recent annual budgets) conservatively generates primary economic activity equivalent to conventional government spending of about $325M per year. That is, comparing 'apples with apples' and taking account of the delay between research and its applications, the short- to medium-term impacts are at least nine times the expenditures. Expressed in yet a third way, if the NSERC expenditure did not exist and governments wished to match the short- to medium-term economic impacts by directly injecting cash into the economy, they would have to spend nine times as much as NSERC actually spends. When we include consumer multiplier effects (the recirculation of money as it is spent by its original recipients), the dollar numbers are multiplied by a factor of about 3 – 5. The total impact is thus in the region of $1-1.6B per year!

The largest impact of those studied is from spin-off companies. This accounts for two-thirds of the foregoing numbers, even without considering companies which themselves spin-off from the initial spin-off companies. The next largest effect is the economic value of graduate student training. While this is only about 15% of the total impact, it still exceeds the physics Research Grants budget by a wide margin. Other impacts considered include technology licensing and spending by foreign students. Medium-term impacts on existing companies (other than via technology licensing) as studied by Mansfield in the U.S. cannot be estimated by a study of this scope, but arguments are presented to suggest that this may be another very large effect. The impact of the Research Grants program in enabling concurrent or later Research Partnership efforts is also not included, nor is faculty consulting.

Reasonably accurate comparisons can be made with other disciplines only for spin-off companies, but this is by far the largest impact. Based on NSERC data, the revenues of physics-generated companies represent 18.1% of the revenues associated with all NSERC disciplines, which is significantly more than physics' share of the Research Grants budget (14.7%). This seems rather remarkable, given the 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 (5.7% versus 0.5%). Using more recent revenue data, the spin-off company impact for physics as a whole is well over six times the annual physics Research Grants budget.

The present study, while broader in scope than most previous studies, is approximate and primarily addresses physics. One objective of the work is to stimulate more detailed studies. Major NSERC studies are therefore recommended to better quantify several of the impacts for the NSERC disciplines as a whole. This could help greatly in making a still better short- to medium-term economic case for the NSERC Research Grants program. The specific recommendations follow.

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RECOMMENDATIONS OF THE ECONOMIC IMPACT STUDY

Recommendation 1. NSERC should build on the excellent start made with *Research Means Business*, and undertake a broader study. This should consider second-generation spin-offs, take better account of companies started by graduate and other students, and perhaps improve on our preliminary analysis regarding the time dependence of revenues.

Recommendation 2. 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.

Recommendation 3. 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.

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

Recommendation 5. NSERC should initiate a proper study of the extent to which NSERC research in all disciplines creates economic impacts related to spending by foreign students in Canada and reduced spending by Canadians studying abroad.

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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 occur without NSERC support of physics via the Research Grants program[a]. Such a focus is of great importance from a policy standpoint, since it directly addresses the cause and effect relationship between NSERC support of physics and many of its short- to medium-term benefits to Canada. However, there are both advantages and disadvantages in constraining the study in this way. 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' (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 (i.e. other efforts may have been necessary), but for which we can argue that the NSERC program 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 regarding the short- and medium-term importance of NSERC physics Research Grants to the economic benefit of Canada.

It should be strongly emphasized 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. Such impacts often include the generation of 'platform technologies,' i.e. technologies which are so new or revolutionary that they themselves give rise to a host of other technologies and applications. Examples of such physics-based technologies are the transistor and the laser, or in earlier days X-rays and cathode ray tubes. Equally important is the physics which gave rise to major instrumentation and methodology advances such as NMR, magnetic resonance imaging, ion implantation, neutron scattering, and recently 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 by Rosenberg [1, 2], "*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*". Rosenberg [1] goes on to mention spectroscopes, electron microscopy, X-ray crystallography and NMR. He 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 a Nobel Prize in physics. Similarly, methodologies originating in physics play major roles in industry and the economy. Rosenberg [1] points out, for example, that ion implantation originated with high-energy physics. A very recent example is the World Wide Web, which also spun-off from high-energy physics.

The reasons why a study like ours cannot quantify impacts of the type described in the preceding paragraph include (i) the difficulty of attributing such large and diverse impacts to specific national programs, as previously mentioned, or sometimes even attributing them to specific disciplines, (ii) the difficulty of measuring the research investments and 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 make quantitative estimates of a much wider range of impacts than most previous studies, including the economic impact of graduate student training, in the hope that this will stimulate better estimates of the

[a] In the NSERC context, the term 'Research Grants' can mean the whole program (including equipment grants, MFA, etc.) or the 'operating grant' portion of this program. We shall use it to mean the entire program.

various impacts for the NSERC disciplines as a whole, (ii) to explicitly consider the incrementality of the impacts, (iii) to compare government expenditures with economic impacts on a reasonably equivalent basis. We address this last point in detail in section 1.1.

The definition of academic physics used in this study follows that used for the overall Review of Physics. It includes all work funded by GSC's 19, 28 and 29 (SubAtomic Physics, Condensed Matter Physics and General Physics) and their precursors. It also includes the Space / Atmospheric Physics and General Relativity portions of GSC 17 (Space and Astronomy). (For brevity, we shall frequently refer to the included group of topics as 'Space Physics'.) As in the Review generally, this definition (like any other) will miss some excellent physicists, but it is both tractable and fairly comprehensive.

Many of the arguments which follow are quite detailed. To assist readers who may not wish to explore all matters in depth, we have therefore placed brief summaries at the start of most of the sections.

1.1 Comparing Apples with Apples: The Canadian Situation

Summary. To compare the economic impacts of research with the NSERC expenditures which give rise to them, the correct measure of impact is the total of the business revenues produced. This is so because most Canadian research-based innovations establish or protect Canadian economic activity which would otherwise have occurred abroad. Even where businesses are not directly involved, the impacts can usually be expressed in an equivalent form. When estimating the ratio of impacts to expenditures in this way, the normal economic multipliers arising from recirculation of cash in the economy roughly cancel out, since they apply roughly equally to business revenues and to government expenditures.

It is essential to compare government expenditures with economic impacts on a reasonably equivalent basis. This point 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 technology licenses? What measure does one use for the impact of graduate student training? Very frequently, these points are glossed over in economic impact studies. For example, estimates of (S x N) (where S is the average salary received by university graduates, over and above what they might have received without higher education, and N is the number of students graduating per year) are often compared directly with annual government expenditures on universities, with no stated justification that the two quantities are properly comparable. Likewise, expenditures on R&D are variously compared (often without explicit justification) either to corporate profits or to revenues, or 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.' 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 cases this would be reasonable. In fact, however, 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 (the grocery store, landlord, employees, etc.) 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 (for example, many equipment purchases in the case of research) will be imports. From the standpoint of the Canadian economy, the process therefore 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 which starts in B.C., say, may leak out of B.C. but remain in Canada. It also depends on the nature of the original expense. For jurisdictions of the size of countries or major Provinces, this multiplier 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.

A non-capital initial government expenditure of $X, then, will create first-level economic activity of $X, largely in Canada, followed by multiplier effects. If the initial outlay is balanced by a reduction in a government transfer to another program or region, or by increased taxation, the effect of this will be -$X. Thus, if multipliers are similar, the net effect is zero as would be expected. (To put the same idea another way, any expenditure has an associated 'opportunity cost': something else may not get done.) However, if the initial 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.

To compare the original government expenditure with the subsequent effects, one can ask how much net incremental 'primary' cash is injected into the Canadian economy from those subsequent effects. If (i) the subsequent effects are mainly the creation of net additional business revenues, (ii) <u>those revenues are primarily from exports and do not merely replace an export which would have continued anyway</u>, and (iii) the business revenues are spent largely in Canada, then the business revenues 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 determine the ratio of the impacts to the government expenditure as if the multipliers were equivalent is probably a conservative assumption: high-tech corporate multipliers are probably [5] higher than typical 'low-tech' government expenditures. Gardner and Hanlon [5], for example, argue 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. Three B.C. universities [6] suggest a multiplier of 2.5 to 3.5. Since both these estimates are for the B.C. economy, the Canadian numbers are expected to be somewhat larger: expenditures may leak out of B.C., but remain in Canada.

Thus, leaving aside timing differences, which are dealt with in section 1.5, we can properly (and conservatively) compare the annual NSERC physics Research Grant budget ($X) with the annual business revenues ($Y) generated as a result. This is because the economic activity and benefits produced by the $Y will be at least similar to those which would be produced by a government expenditure of $Y, when in fact only $X was spent.

We emphasize again that this approach probably only works if the corporate revenues involved are incremental exports (or import replacements). 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.[b] Even if a particular technical innovation merely replaced one Canadian product with an improved Canadian product, it can be argued [7] that, in all probability, failure to make the replacement would quickly lead to loss of the market to a foreign competitor. Furthermore, in high-tech situations, even products purchased by Canadian customers could well have been purchased from foreign suppliers in the absence of the Canadian supplier. 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. 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 an assumption which is already implicit in at least one NSERC study on spin-off companies [8]: 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. Others might indeed have developed the later areas in the absence of

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

the company in question, but the chances are high that they would not have been Canadian. Thus, such revenues are still incremental and probably would not have occurred without the original NSERC work.

To repeat, we believe that an assumption of nearly 100% incrementality 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 calculate the ratio of impacts to expenditures ignoring consumer multiplier effects: the latter would apply to both kinds of cash injections, with the high-tech ones probably having somewhat higher multipliers.

1.2 Second-Order Effects

Summary. For practicality reasons, we do not consider second-order effects like companies spun-off from companies that themselves spun-off from NSERC research, even though such effects can be large. Nor do we generally consider the 'social returns' on innovations (the benefits accruing to the economy over and above those reflected in the innovating company's revenues). Such omissions, which could be reduced by a more detailed study, will make our estimates decidedly conservative.

There will certainly be a few cases where there may be incomplete incrementality or other factors which could 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 aspect is that we very largely ignore second-order impacts, which can in fact be large.

Second-generation 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-generation spin-off. An informal study by the University of Saskatchewan Physics Department, for example, found [9] that just one of the companies (SED) in our spin-off study has spawned approximately 20 additional companies in Saskatchewan! Another analysis [10] found that the total revenues of 12 of these second-generation spin-offs were at least as high as that of SED itself. Likewise, a study [11] on the many spin-offs from the University of Cambridge, England, indicated that first generation companies numbered less than 40 in the 1980's, while there were already over 200 later-generation companies. Furthermore, the latter included some of the most important successes.

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 ([12-14] for example) that the impact of an innovation on primary economic activity is far higher than the impact on the innovating company. This is because improved products and processes reduce the costs to consumers and also (although this is not entirely without controversy [15]) 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 [13] investigated a range of innovations and estimated that the average 'private returns' (i.e. returns to the innovating company) were 25% p.a. and that the average social returns were 56% p.a. 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, the private rate of return was 4% p.a., but the social rate of return was 116%![c]

It is very difficult to estimate the additional impact of such effects without detailed and time-consuming case studies. Neglecting them should much more than make up for any overestimates which could creep into our study from other factors and should ensure that our ultimate estimates are decidedly conservative.

1.3 The Nature of Economic Analyses

Summary. Economic analyses of research impacts cannot be precise. We shall therefore be conservative enough that our estimates will almost certainly be lower limits.

Since many readers may not have been exposed to detailed economic analyses, we will first explain 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 the final estimates in most such studies are quite approximate. 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. In doing this, one tries 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: our estimates should certainly be conservative lower limits.

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 approximate estimates of the impact of NSERC-supported physics where, in many cases, none seems to have existed before.

1.4 Rates of Return on Investment

Summary. We shall calculate absolute dollar impacts, but will not attempt percentage rate of return calculations, since such calculations would probably be misleading.

There have been many studies of the annual rate of return on investment in various kinds of R&D, and we shall refer to some of them in later sections. Most relate to 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 [12] by Mansfield in the U.S. which suggested a rate of return of 28% p.a. on worldwide university research, 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 on the whole economy[d], and usually show very good (often >40%) social rates of return.[e] While Canadian equivalents of these studies would be of interest, they are

[c] It may not be appropriate in principle to consider much of this additional social return 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-Canadians; 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-generation spin-offs, however, so long as they are Canadian; for these, the difficulties are merely practical.

[d] 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 [16]. There have been suggestions [17] 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.

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

certainly far beyond the resources of this work. Furthermore, much of this work (including the 28% figure) 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 always 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

Summary. Standard methodology is used to convert past and future cash flows into their 'present values.'

Activities undertaken and paid for today often create impacts and benefits in the future. In order to compare the impacts with the initial expenditures, we shall employ standard 'discounted cash flow' calculations. These simply recognize that $1 received in say ten years is worth less than $1 received now. That is, the 'present values' are different. 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 grossing it up by a similar factor. Analogous to the previous example, the present value of $1 spent 10 years ago, assuming a 10% rate, would be $1*((1.1)^10), or $2.59.

In fact, we shall generally use a discount rate equal to the inflation rate plus 3% p.a., which is historically a typical real rate of return for low risk[f], medium- to long-term investments. It has been used, for example, in earlier studies [18] on the impact of undergraduate training. In some cases, future 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 <u>after</u> inflation, then the inflation rate would cancel out and the net discount rate applied would be 3% p.a.

1.6 The NSERC Physics Research Grants Budget

Summary. Recent total annual spending for physics within the NSERC Research Grants program has been about $36M p.a.

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

[f] The economic risks associated with any individual's research program are high of course. However, as will become clear, the risks associated with a large, diversified effort like that supported by the physics Research Grants program appears low; this is so because the impacts are so large and broadly based. The very rapid initial returns discussed in section 2 alone reduce the risks to low levels. More importantly, the use of low-risk rates really reflects the rates at which a government can borrow money, rather than the uses to which that money is put.

To avoid biases due to year-to-year budget fluctuations, we generally used average GSC budget numbers [19] 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 slightly different from recent numbers. The annual SubAtomic Physics (SAP) budget was calculated as simply the average of the total envelope (and pre-envelope) expenditures in these years [20]. For the other GSCs, 'operating' grants and equipment grants were first added together. Then, to allow for other Research Grant program elements which are not easily attributed to specific GSCs, we multiplied these non-SAP totals by 1.105. This factor is [19] 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 17 spending by 25.5%; this is equal [20] 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 $36M p.a. Table 1 (section 3.1) gives a breakdown between physics sub-disciplines.

Depending upon how one wishes to use the results of the present study, one might recall that universities contribute 'infrastructure' support to the work supported by NSERC and that the magnitude of this support may be very roughly equal to the NSERC spending. For some purposes, therefore, one might wish to compare the impacts discussed below with the NSERC grants <u>plus</u> the infrastructure support, or with very roughly $70M p.a. rather than $36M. (To be consistent, impact #2 discussed below would then also be doubled.) Some of the impacts (notably graduate student training) are also partly dependent on NSERC Scholarships and Fellowships. However, the total applicable budget for all disciplines is only about 20% [19] of the Research Grants program budget; within physics, we would therefore doubt that these expenditures exceed about $7M.

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

2. THE DIRECT IMPACT OF THE EXPENDITURE ITSELF

Summary. The NSERC expenditure itself directly creates economic activity (salaries, purchases, etc.) similar to that produced by most other government outlays of the same size. This direct impact is often neglected.

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 [21]. That is, the initial expenditure creates incremental economic activity (salaries, purchases, etc., together with normal consumer multiplier effects) comparable to the impact of a similar direct expenditure on a different government program, such as a social payment, government procurement, etc. Of course, if the expenditure is offset by an expenditure cut elsewhere or by a tax increase, the net immediate 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 later impacts from the actual research.

This direct impact, while in a sense obvious, is frequently neglected. It virtually guarantees that government expenditures on R&D (like other capital expenditures which are largely spent in Canada) must be at least as cost-effective as most forms of (non-capital) government outlays: an expenditure is made and there are immediate impacts. Like other capital outlays, the later impacts of research spending are, in a sense, a bonus.

3. THE IMPACT OF SPIN-OFF COMPANIES

Summary. Spin-off companies are introduced and defined.

By a spin-off company, we mean a new company (or, rarely, a separate new division of an existing company) founded as a direct result of research performed by the holder or former-holder of an NSERC physics Research Grant. Usually, the company is founded by the grantholder, although in a few cases companies founded by students or others as a direct result of such work may also be included. Sections 4 and 5 will consider situations where research is exploited by an existing company.

Spin-off companies are one of the easier impacts to measure, since they give rise directly to Canadian corporate revenues. As we have argued, these can be compared almost directly with the underlying government expenditure. Although there is a tendency to downplay it in some recent work [2], the impact of spin-off companies can be high. In the U.S., for example, a recent report [22] 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"

Summary. The data from a 1995 NSERC publication on spin-off companies, *Research Means Business,* have been analyzed. Despite the basic and long-term nature of much of physics, the physics share of the all-discipline spin-off revenues (18.1%) is significantly higher than physics' share of the Research Grants (14.7%). General/Condensed Matter Physics has over one-eighth of the revenues from all disciplines, but only 6% of the grants. The corresponding numbers for Space Physics are 5.7% versus 0.5%. In absolute dollar terms, the annual spin-off revenues for Condensed Matter/General Physics in *Research Means Business* are about five times the corresponding NSERC expenditures. For Space Physics, the factor is 25. For physics as a whole, the dollar revenues are three times higher than the expenditures. These numbers are updated and extended in sections 3.3 and 3.4.

Our initial analysis focuses on a 1995 study [8] by NSERC, *Research Means Business*. This attempted to identify all known cases of for-profit spin-off companies which were related to NSERC-supported researchers in any discipline, and which had more than 5 employees. That is, there was no attempt to artificially balance the number of companies by region, discipline, etc. [23]. A few 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[g]. The study is very helpful, since it relates to all NSERC disciplines and thus allows comparisons between disciplines. An NRC database [25] 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 have been derived from *Research Means Business*[h] and compared with the Research Grants budget (section 1.6) for the physics disciplines[i] and for all disciplines. Where it was not obvious, we obtained information from NSERC [26] as to which GSC supported the company's founder. Consistent with our definition of physics in section 1, we included only those companies whose founder was supported by GSC 19, 28 or 29 (or their precursors) or the Space/Atmospheric/General Relativity portion of GSC 17.

[g] One study [24] of Canadian firms founded by 'academic entrepreneurs' found that 45% of them were started while the founder was a student, Post-Doctoral Fellow, Research Assistant, etc. 16% were founded by M.Sc. students and 10% by Ph.D. students.

[h] For six of the companies, representing 32% of the revenues, only employee (rather than revenue) information was available. In these cases, we followed apparently the same estimating procedure as used in the NSERC report: the average annual revenue/employee for the other companies in the report ($127K) was multiplied by the number of employees of the company in question. In all, twelve physics-related companies are involved in Table 1, out of 82 (from all disciplines) featured in the NSERC report. With the stated or estimated revenues in brackets, they are: CTF Systems ($8.3M), Dewey McMillin ($0.15M), Moli Energy ($19.1M), Quantum Technology ($0.75M), Solar System Assemblies ($1.3M), TIR Systems ($1.9M), Vortek Industries ($3.2M), ITRES ($1.9M), SED Systems ($32M), Optech ($6.4M), Sciex ($65M), and Waterloo Scientific ($1.4M). The key founder of Sciex (Barry French) had been supported by two GSCs, one of them Physics [26]; only 50% of the Sciex revenues ($32.5M) were therefore counted in our study.

[i] We have combined Condensed Matter and General Physics. To attempt to split them would be difficult and scarcely meaningful in several cases. Moreover, these two GSCs were actually one when many of the larger companies were spun-off.

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

Source of Work (Sub-Discipline)	General/ Condensed Matter Physics	Space Physics	SubAtomic Physics	Total Physics	All NSERC Disciplines
Total Spin-Off Company Revenues p.a. ($M)	74.8	33.9	--	108.7	600
Research Grants, incl. Equipment & allowance for all other program elements, p.a. ($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%

Two sets of very important conclusions can be drawn from the data in Table 1:

(i) Despite the basic and long-term nature of much of physics, all but (arguably) the most basic subdiscipline (SubAtomic) has a much higher percentage of the spin-off revenues than its share of the total Research Grants budget. General/Condensed Matter Physics has over one-eighth of the revenues from all disciplines, but only 6% of the grants. The situation for Space Physics is even more remarkable: 5.7% versus 0.5%. The share of the revenues for physics as a whole, including SubAtomic Physics, is 18.1%, which is 25% higher than physics' share of the Research Grants (14.7%).

(ii) For Condensed Matter/General Physics, the annual dollar revenues from spin-offs are about five times the corresponding NSERC expenditures. For Space Physics, the factor is 25! For physics as a whole, including SubAtomic Physics, the dollar revenues are three times higher than the expenditures.

While we have not yet considered the delay between research and revenues (the preceding analysis simply compares current annual revenues against current annual expenditures), this is a remarkable result for only one impact. Again, recall that we believe these numbers (revenues and NSERC expenditures) can be directly compared. 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.[j]

Finally, although SubAtomic Physics is not represented in *Research Means Business*, a good case can be made (section 3.4) that two companies spun-out of TRIUMF are in fact largely attributable to this subdiscipline and that $16.5M of their annual revenues should be attributed to NSERC SubAtomic Physics.

3.2 The Delay between Research and Revenues

Summary. Section 3.1 compared current annual impacts with current annual expenditures. We now consider the correct comparison, which is the ratio of the present value of the spin-off company revenues to

j 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.

the present value of the Research Grants that gave rise to them. The detailed but approximate calculation shows that the current annual comparison of section 3.1 is a very conservative surrogate for the correct comparison. Since current annual numbers are vastly easier to obtain, we shall continue to use them.

Generally, we are attempting in this study to compare today's Research Grants outlays with the present value of the immediate and later impacts, using discounted cash flow concepts (section 1.5). When we consider the economic impact of graduate student training (section 6), for example, we shall discount the future economic value of the graduates' working lives to a present value. With spin-off companies, there is of course a delay between the NSERC expenditures and the initial revenue flows. In most cases, it has also taken many years for the revenues to grow to their present levels. One can therefore ask whether the comparison of current impacts against current expenditures in the previous section is valid.

We cannot directly predict the value of the companies which may be set up now or in the future based on current Research Grants. However, we can use the existing companies as a surrogate. Specifically, we can ask: (i) what is the present value of the Research Grants expended in the period during which these companies had their origins?, (ii) what is the present value of the companies' revenue streams which have occurred to date <u>plus</u> those which we might conservatively project for the <u>same</u> companies in the future? We can then see whether the ratio of the two quantities is reasonably approximated by the current annual ratios in section 3.1. The calculations will suggest that using the current annual ratio is probably highly conservative. The arguments are detailed and somewhat complex, and the more casual reader may wish to take the previous statement on trust and move straight to section 3.3.

The calculation, of course, is an estimate of returns from earlier expenditures. However, given the recent much increased emphasis on the applications of academic research, we would argue that the impacts of present and future grants are likely to be at least as good as those seen in the past. Since most of the information in Table 1 is for 1995, we shall use 1995 for all 'present' values.

<u>3.2.1 The Period Involved</u>. The companies included in Table 1 were founded between 1970 and 1993 [8]. In 1995, their average age was about 14 years. Given the rather direct connection between a researcher and a spin-off company, let us assume that the bulk of the research which led to any given company occurred in a fairly short period (say 4-5 years) preceding incorporation. For simplicity, we will approximate this range of dates by treating all this research as occurring two years before incorporation. Since the information in Table 1 comes mainly from 1995, it follows that our comparison should extend from 1968 (two years before the first company was incorporated) to 1993 (two years before 1995), a 26 year period. Research done later than this would almost certainly show up in incorporations and revenues after 1995.

<u>3.2.2 The Present Value of Previous Years' Physics Research Grant Spending</u>. We have not been able to obtain precise NSERC / NRC physics Research Grant numbers for years prior to 1986, but we have found sufficient data in previous reviews of physics that we have been able to make reasonable estimates. [k] These will not be accurate in the early part of the period, but they should be quite good enough for our present purposes. The total physics Research Grants for the period 1968-1993 (26 years) are estimated as $583M, or 16 times the recent annual Grants.

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[k] We have NSERC data [20] for SubAtomic physics back to 1980. An earlier CAP review of physics [27] reprints part of the 1979 Fife report, which reports a total SubAtomic budget for 1979 and breaks it into nuclear, high energy and intermediate energy physics. The same CAP report [27] traces the high-energy portion of the budget back to 1973, and we assume that the total SubAtomic budget varied similarly during the same period. For Condensed Matter, General Physics, and Space Physics, we have NSERC data [19] back to 1986 (the old Physics GSC split into Condensed Matter and General during this period). We also have a 1980-81 figure for Physics from another portion of the earlier CAP review of physics [28]; between this and the start of the NSERC data, we made a linear interpolation and we assumed that Space was roughly proportional to this. A third part of the same CAP report [29] gives data back to 1972-73 on the number and size of Atomic and Molecular Physics (AMP) grants; using a three-year moving average of the product of these, we can get a reasonable estimate of the variation of the AMP budget and we assume that the total Physics and Space budgets varied similarly. Prior to 1972-73 we have no data, so we simply assume a variation proportional to the Consumer Price Index.

Next, we must convert each year's grants to the present value in 1995. As discussed in section 1.5, we gross-up the expenditures by 3% p.a. plus the inflation rate, and compound for the years between the expenditure in question and 1995. The inflation rates used are Statistics Canada ("Statscan") all-Canada 'average' rates [30]. When this is done, the present value in 1995 of the total physics Research Grants for the period 1968-1993 is estimated to be $1,619M, or about 45 times the recent annual grants.

<u>3.2.3 The Present Value of Estimated Past and Projected Future Revenues of the Companies in Table 1</u>. The calculation of the present value of the companies' past revenues is in principle straightforward, but in practice difficult, because it would be very time-consuming, if not impossible, to assemble the annual data for each company. In fact, as we shall see, the contribution of past revenues is a comparatively small part of the total, so we shall use a reasonable formula to approximate it. The calculation of future revenues is, of course, even harder and again we shall use a simple, yet very conservative, formula approach.

A very simple approach to estimating past annual revenues would be to assume a constant geometric increase in revenues over the life of the company, i.e. a constant growth rate. This must be bounded by a finite value at the start, and one might take say 100K per year, or roughly the likely output of one individual. This would be a very conservative approach, since the low starting point and the geometric assumption would ensure that only the most recent years would contribute significantly to the total, even before discounting. A marginally less conservative and perhaps more reasonable assumption might be to impose a $1M p.a. first term on the geometric progression, and to assume a linear increase between the founding of the company and the point when geometric progression starts. (Mechanically, the year when the geometric progression starts is set by requiring a smooth transition between the two regimes.) This approach is more reasonable in that it will tend to reproduce the 'hockey-stick' shape of the growth of many corporations: slow steady growth for a while, followed by accelerating growth. These two simple models produce total revenues to 1995 of $525M and $640M (5-6 times the annual 1995 revenues shown in Table 1). Next, we must convert each year's revenues to 1995 present values, as we did for the NSERC outlays. The final result from the two models is $660M and $880M (6-8 times the annual 1995 revenues). For further calculations, we will take the mean, or $770M.

The next step is to estimate the future revenues. The growth rates implied by the above estimates are typically over 20% p.a., and are generally not out of line with the actual growth that has occurred since 1995 (section 3.3). However, let us make an extremely conservative assumption that the future growth rate will average only about 5% p.a., or more precisely 3% over inflation. We will also discount future revenues by 3% p.a. plus inflation as usual. Finally, let us assume that these companies, which have been built-up over 26 years, will have a half-life of say another 26 years. That is, we assume that companies that would otherwise have had half of the revenues will go out of business during this next 26 years. We implement this by imposing an additional 2.7% p.a. deflator to the projected earnings (1.027^26 = 2). This half-life is probably highly pessimistic. Denys Cooper of NRC's IRAP program has maintained a major database of high-tech startup companies for many years; of the 24 physics-related companies in this database,[I] Dr. Cooper indicates [25] that only one has ever gone out of business to his knowledge. Finally, we sum the resulting geometric progression. The resulting discounted future revenues are estimated as 37 times the annual revenues in Table 1, or about $4,020M.

<u>3.2.4 Comparison of Present-Values of Outlays and Impacts</u>. Summarizing the very rough calculations in the last subsections, we estimate the present value of the NSERC/NRC physics Research Grants from 1968 (two years before the first spin-off company was incorporated) to 1993 to be $1,619M or 45 times the recent annual budget. We estimate the present value of the past and projected future revenues of the companies created during this period (those contributing to Table 1) to be $770M + $4020M or about $4800M (7 plus 37 = 44 times the annual 1995 revenues). The ratio of impacts to expenditures is thus estimated as 4800/1619, or 3.0, compared with the current annual estimate (section 3.1) of 108.7/36, or also 3.0!

[I] This includes companies which, while physics-related, were not based directly on work supported by NSERC physics grants.

We again emphasize that the above calculation is quite extraordinarily conservative. For past years, it uses very rapid geometric growth rates (typically over 20% p.a.) which quickly extinguish the impacts as we move back from the present. On the other hand, it assumes that future growth is limited to only about 5% p.a.; even this is also offset by a nearly 3% p.a. deflator to allow for the possibility of companies going out of businesses.

The precise agreement between the above calculation and section 3.1 is, of course, fortuitous. However, the calculation, approximate as it is, suggests that our steady state comparison of impacts and costs (i.e. our comparison of the current annual revenue numbers in Table 1 with the recent annual NSERC outlays) is conservative. That is, it does not overstate the proper comparison, which would be the likely present value of revenues from future companies compared with current annual outlays.

3.3 Latest Revenues of the Companies in 'Research Means Business'

Summary. Updating Table 1 to allow for subsequent company growth increases the total revenues from $108.7M to $183M, or five times the annual physics Research Grants budget.

We have updated the revenues in Table 1 to allow for subsequent company growth, since the NSERC numbers are from 1993-95. Of course, it is not possible to compare this additional data with all-discipline numbers.

We have been able to obtain more recent numbers [31] for companies representing 94% of the revenues in Table 1. Many of these companies have shown rapid growth. Where only employee numbers were available, we again converted this to estimated annual revenues at the *Research Means Business* average of $127K / employee. Conservatively assuming all other revenues have remained unchanged, we estimate recent total revenues[m] to be $183M (5.1 times the recent annual NSERC physics Research Grants). These numbers break down into $140.5M for Condensed Matter/General Physics and $42.2M for Space Physics (respectively 9.4 and 32 times the recent corresponding Research Grants budgets).

3.4 Other Companies

Summary. Adding other companies that were not covered by Research *Means Business* increases the total annual physics-based revenues to $222M, or 6.2 times the total annual physics Research Grants budget. The ratio of annual revenues to annual budgets rises to 10.5 for Condensed Matter / General Physics, 36 for Space Physics, and 0.83 for SubAtomic Physics.

Even the increased numbers in section 3.3 are conservative. As previously mentioned, Denys Cooper of NRC maintains a major database of university spin-off companies. He does not include companies started by graduate students. He has pointed out [25] that the total 1994 sales of those companies (not including Sciex) whose products are primarily based on physics, regardless of the originating professor's department or GSC, were about $240M.

Dr. Cooper's additional companies can certainly be argued to be part of the real contribution of physics to spin-offs. However, most of them do not fall under the definition used in this study (companies started by researchers supported by physics Research Grants). On the other hand, the questionnaires utilized by the discipline SubCommittees during the information-gathering phase of the present Review uncovered several others. With the kind help of Meredith Burton (NSERC), we have investigated both the revenues and the origins of the companies suggested by Dr. Cooper and those uncovered by the subdiscipline SubCommittees. We have also included several recently discovered by Ms Burton. Omitting companies where any serious doubt seems to exist as to the role of NSERC physics-supported researchers[n], this process adds another eight companies [32]. The latest total annual revenues for these are \$22.8M[o], \$17.7M for Condensed Matter/General Physics and \$5.1M for Space Physics.

The basic question in the present study is the extent to which NSERC physics Research Grants are a necessary but not always a sufficient condition for various impacts. A very good case can therefore be made that some of the economic impact of TRIUMF's technology transfer efforts should be included. After all, TRIUMF's main *raison d'etre* is to support academic research in various fields of physics, primarily SubAtomic. Moreover, the efforts of TRIUMF are carried out very much in conjunction with NSERC-supported academic researchers, and are supported by GSC 19. TRIUMF's licensing activities will be discussed in section 4.5, but the Director of the TRIUMF Ventures Office [33] feels that two of their Canadian licensees[p] are more properly dealt with as spin-off companies. Moreover, the Ventures Office believes that almost 100% of the TRIUMF-licensed revenues of one of these companies and about 50% of the other's should properly be attributed to NSERC work. Using this allocation in conjunction with typical recent annual revenues of these companies (the revenues fluctuate considerably from year to year) [33], we add another \$16.5M[p] to the total spin-off revenues attributable to NSERC. This amount is primarily attributable to SubAtomic physics.

<u>We thus end up with grand total annual revenues from spin-off companies</u> (not counting those of Dr. Cooper's companies which do not fall under our definition) <u>of \$222M p.a., or 6.2 times the recent annual physics Research Grants budget. The total for Condensed Matter/General Physics is \$158M p.a., 10.5 times the corresponding recent annual Research Grants budget, while the total for Space Physics is \$47M, or 36 times the Space Physics Research Grants budget. For SubAtomic Physics, the total is \$16.5M, or about 83% of the Research Grants budget.</u>

3.5 Second-Generation Spin-Offs

It is well to recall again that the above analysis does not take into account any spin-offs from the spin-off companies themselves. As mentioned previously, just one of the companies contributing to Table 1 (SED) has spun-off [9] approximately 20 additional companies; in 1993, the total revenues of 12 of them were reported to exceed that of SED itself, which was then \$25-30M [10]. The omission of such companies, and some other approximations that have been made in estimating the impact of spin-offs, leads to our first recommendation.

> Recommendation 1. NSERC should build on the excellent start made with *Research Means Business*, and undertake a broader study. This should consider second-generation spin-offs, take better account of companies started by graduate and other students, and perhaps improve on our preliminary analysis regarding the time dependence of revenues.

3.6 The World-Wide Web

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[m] The updated revenues are as follows, where an asterisk indicates an estimate based on number of employees: CTF Systems (\$10.3M*), Moli Energy (\$48.3M*), TIR Systems (\$6.2M), ITRES (\$2.2M*), SED Systems (\$40.0M: see note in ref. 31), Optech (\$10.0M), Sciex (50% x \$118M). No new information was obtained for Dewey McMillin, Quantum Technology, Solar System Assemblies, Vortek Industries, and Waterloo Scientific, so their revenues were left as in section 3.1

[n] These include Bomem (\$20M), Resonance (8 employees), and Exfo (with an unconfirmed report of >250 employees). We are also aware of SCI-TEC, with revenue of \$4M before its acquisition of a Dutch firm; however, this is a spin-off of SED and we are generally not counting second-generation spin-offs. Also, Focal Technologies (\$5.3M) was founded by Barry Paton of the Dalhousie Department of Physics; however, Dr. Paton was apparently not supported by the physics GSCs considered in this report.

[o] The revenues are as follows, where an asterisk indicates an estimate based on number of employees: Profco \$(0.1M*), Techware/Brooks Canada (\$14.6M), Datec Coating (\$0.25M*), Millenium Biologix (\$1.0M), Corona Vacuum Coaters (\$0.5M), Biomedical Pharmometrics (\$0.44M*), Electrophotonics (\$0.76M*), and Power Lasers (\$5.1M*).

[p] We have carefully reviewed this with the Director of the TRIUMF Ventures Office, but commercial confidentiality requirements prevent us from identifying the companies here.

Finally, although SubAtomic Physics has fewer companies in the preceding analysis than the other subdisciplines, it can make an excellent case for recognizing a portion of the enormous revenues which now flow from the World Wide Web. This technology was not only invented at CERN (where Canadian SubAtomic grantholders play a significant role), but was created precisely because SubAtomic Physics involves such wide international cooperation.

4. THE IMPACT OF TECHNOLOGY LICENSING

4.1 Introduction

Summary. Technology licensing is defined. Canadian university licensing revenues from all disciplines are $11.8M p.a. and rising quite fast.

Where research is not spun-off to a new company (usually involving the key researcher), the corresponding intellectual property may instead be licensed to an existing 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 receive an equity (partial ownership) position in the licensee company.

The U.S.-based Association of University Technology Managers (AUTM) publishes royalty data annually for all member universities in the U.S. and Canada. The total royalties reported by AUTM [34] for Canadian universities for the 1995 fiscal year (the latest for which figures are available) is U.S.$8.59M[q] (about C$11.8M). Unfortunately, no breakdown by discipline is reported, and according to AUTM [35] none is available here or in the U.S. The royalties are rising quite fast, with the corresponding figures for 1991-94 being C$3.9M, $5.1M, $6.7M and $7.6M. 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 direct benefit to Canada seems likely to approximate the license revenues received, rather than the associated company revenues.

4.2 All-Discipline Revenues

Summary. The Canadian corporate revenues generated by technologies licensed by Canadian universities total about $240-480M p.a. This encompasses all disciplines, including those funded by MRC.

To estimate the corporate revenues underlying the all-discipline royalties reported by Canadian universities, one must make an assumption about the ratio between the two, i.e. about the royalty rate. AUTM [36] reports, apparently with approval, a study carried out in the U.S. that 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 are not always simple percentage royalties. However, to get a rough feel for revenues, we will assume a possible range of 2 - 4% for the royalty rate, although we suspect that the correct number is in the top half of this range.

The company revenues associated with the 1995 Canadian university royalties are thus estimated as $295-590M 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 no published data on this point, but the average proportion of such companies 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 $240-480M for

[q] This does not include U.S.$1.95M for Mount Sinai Hospital.

the 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 can be compared with the $600M figure [8] for spin-off companies from the NSERC disciplines alone.

4.3 Physics Revenues

Summary. Based on our own survey, the Canadian revenues generated by licensed technologies which are based on physics research are estimated as roughly $5-10M p.a.

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. To do this, a questionnaire was developed and sent to all Canadian universities believed to have a Technology Transfer Office (TTO). As mentioned previously, we also asked about the Canadian content of the revenues, as well as their likely incrementality. Because of the involvement and persistence of the TRIUMF people, who are well known in their community, we eventually received replies from eight university TTOs representing 55% of the 1995 Canadian AUTM license revenues. These replies reported $133,000 of royalties from physics-related inventions, although we suspect that a few respondents could not trace their innovations to the originating disciplines. Thus, we suspect that the foregoing number is low. In most cases, the incrementality was judged to be very high.

Taking the data at face value, and (i) applying the 80% Canadian estimate, (ii) assuming a 2-4% royalty rate, and (iii) grossing-up the result by 100%/55%, we arrive at a rough estimate of $5-10M p.a. for the Canadian corporate revenues from licensed physics technology. This does not include TRIUMF itself, which we discuss in section 4.5. This figure should be treated with caution, given the large uncertainties. However, it will not form a large portion of the total estimated impact of physics, so it is 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 $5-10M p.a. estimate, like the spin-off estimates, should be corrected for discounting effects associated with the delay between research and revenues. However, we have shown (section 3.2) that the spin-off company impact does not seem to be reduced by these effects, and (particularly given the inexact nature of the licensing estimate and its low total) we doubt that any significant correction is worthwhile here. If licensing revenues were a more significant impact in any future study, this point would need to be revisited.

4.4 The Future

Summary. Revenues associated with licensed technologies are likely to grow rapidly. NSERC needs to receive good, regular information on such revenues.

While our incomplete licensing data do 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 small for long. The average license revenues reported to AUTM by our own respondents had doubled between 1994 and 1995, and the total they reported to us is 50% higher again. Also significant are the 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 the latest (1995) Canadian revenues of about C$12M. 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 10:1, all this suggests that Canadian revenues could well continue to rise quite rapidly in years to come. Economic activity associated with licenses could therefore become a significant justification for NSERC expenditures. This leads to Recommendation 2:

> Recommendation 2. 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

Summary. The inclusion of some of TRIUMF's licensed technologies adds $2M p.a. to the $5-10M physics-related revenues estimated in section 4.3.

As indicated in section 3.4, a good case can be made that some of the economic impact of TRIUMF's licensing efforts should be included in the present study. 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. $16.5M of the Canadian revenues has already been recognized in section 3.4, since these companies are really spin-offs. Other Canadian licensees are generating an additional $3M p.a. Furthermore [33], associated development contracts held by TRIUMF generate over $1M p.a., almost all of it from outside Canada. If we allocate roughly 50% of the total $4M to the Research Grants program, we have an additional $2M impact. It is worth noting in passing that the Canadian TRIUMF spin-off company revenues, plus the $4M above, are equivalent to well over half of TRIUMF's annual budget. Of course, only a small portion of this is received by TRIUMF.

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

5.1 Introduction

Summary. The short- to medium-term impacts of university research on existing companies have been studied by Mansfield in the U.S. and have been shown to be very large. This does not include long-term, revolutionary impacts like the transistor, laser, etc.

This impact represents the intermediate case between (i) the kinds of impacts discussed in sections 3 and 4, 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, and we shall first review this U.S. work.

In a particularly well-known paper [12], Mansfield studied firms in seven U.S. 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 U.S. industries as a whole, new <u>products</u> first commercialized in <u>only a four year period</u> (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. Another $17B p.a. were developed with very substantial aid from recent academic research. These industries experienced a further $7B and $11B p.a. in savings due to new <u>processes</u> which could not have been developed without academic research or which needed very substantial aid from such research.

In 1995, Mansfield [37] reported that he was updating these U.S. 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 [12] went on to estimate the rate of return from worldwide academic research in 1975-78. He obtained about 28% p.a., if benefits to users were included (i.e. the social rate of return, section 1.2), and about 10% if these 'secondary' benefits were ignored. These estimates, as we have commented elsewhere, rest on some rather large assumptions and have been criticized, but they are the source of the 28% figure that is so widely quoted.

The foregoing U.S. work does not distinguish between different academic disciplines. In later work [38], Mansfield attempted to obtain some information on this point by asking U.S. companies to name specific researchers who were important to them. Physics was represented amongst these, but the information given is insufficient to make even a rough quantitative estimate of the contribution of physics to the totals. Moreover, as has been pointed out elsewhere [2], there will be a strong and natural tendency for respondents to recall more recent efforts, such as their own work or downstream university contributions. Consequently, the impact of more basic research in areas like physics is likely to be severely underestimated. As pointed out by a well-known science policy group [2], "*chemistry is not used just in the chemicals sector*" (where it received most if its citations in Mansfield's study [38]) "*but also in a large range of user industries, and other academic disciplines like physics and mathematics have still more pervasive impacts*."

There is evidence that even the large impacts estimated by Mansfield's work are likely to underestimate the real situation, again perhaps because of the respondents' lack of knowledge of the real source of advances. The 'Yale Survey' [39] 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 advances in these disciplines probably arose in, or because of, academia! Interestingly, the importance of physics as a field was widely cited in this work (by 44 industries). It lagged only materials science, of which physics is 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.*"

Impacts of the kind considered in the present section are presumably largely responsible for findings like the recent estimate [40] 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

Summary. A very crude calculation suggests that 'Mansfield' effects in Canada could be of the order of $200M-$4B p.a. for NSERC research. NSERC should study the matter properly.

It seems important to develop a very rough estimate of the magnitude of these impacts 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 must ask how much Canadian innovation might flow from Canadian research, as compared with U.S. innovation from U.S. research. That is, we do not consider "cross-terms" like Canadian innovation from U.S. research and the converse. Amongst other factors, the impact could be proportional to the amount and quality of academic research done; perhaps we might roughly estimate this as say 5% of the U.S.[r] This might at first sight suggest a rough 20:1 ratio between Canada and the U.S. for this impact. However, a case might be made that the

[r] 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 [41] that roughly 3% of papers in Phys. Rev. B, which of course carries papers from around the world, originated from researchers supported by GSC 28.

impact could also be proportional to the receptor capacity of Canadian companies. If estimated by Canadian industrial R&D activity, this 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 could increase the 20:1 'guestimate' above to a ratio of order 400:1 (20x20:1). 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 [38] found that geographical proximity also played a role, but it was far from the only factor.

The total U.S. impacts (in mid-1980's dollars) found by Mansfield and listed in section 5.1 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 previously, 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! This is to be compared to the $600M of revenues estimated by NSERC in 1995 [8] for spin-off companies from all NSERC disciplines.[s]

We make no claims except one for this estimate, which is clearly massively crude. The one claim we do make is that this rather infrequently discussed 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 3. 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

> **Summary. We attempted a small Mansfield study in Canada but encountered difficulties related to those faced by Mansfield. We concluded that the task was beyond our present resources.**

Since there is little data on physics in Mansfield's work, and since no analogous Canadian information of any kind seems to be available, we attempted to perform a much simplified version of Mansfield's studies here in Canada. This we did by approaching[t] a subset of the top 50 R&D-performing companies in Canada and asking them for similar data about physics. We found that companies were sympathetic, but did 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 problem, 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.[u] As mentioned above, we believe that NSERC should look into the matter in much more detail.

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[s] However, since many of the advances considered by Mansfield were fairly routine, it is not clear that our normal high-tech 'incremental to Canada' assumption would apply fully here, nor that the impacts would be as long-lived as those from spin-off companies.

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

[u] It should not be forgotten, however, that much academic work is almost certainly transferred via graduate students. Therefore, the rough calculation in section 6 of the economic value of graduate student training will overlap the Mansfield effects to a small extent.

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

6. THE ECONOMIC IMPACT OF GRADUATE STUDENT TRAINING

6.1 Introduction

Summary. Little or no information exists on the economic value of graduate student training in Canada or elsewhere. Assuming that employment salaries roughly reflect the value contributed by employees, we shall estimate the value by estimating the additional lifetime salaries received by all physics Ph.D.'s and M.Sc.'s in Canada, compared with the same number of B.Sc.'s.

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. A report recently presented to NSERC [4] comments that "*While it is easy to measure inputs and outputs (e.g. number of students entering and graduating, respectively), measuring the impacts 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.

Our approach to estimating this impact is somewhat similar to the methodology used to estimate the value of undergraduate education in some earlier reports ([18] for example). However, we are not convinced that a proper 'apples-to-apples' comparison with the associated government expenses is always made in these studies.

In common with these earlier studies [18] on undergraduate degrees, the basis for our impact estimate is the assumption that employment markets pay roughly for value received. Thus, the 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 estimate and multiply the results by the number of people involved. We then allow roughly for emigration and try to fit the result into our primary economic impact model.

The increased level of job satisfaction which may be enjoyed by the holders of higher degrees could translate into a willingness to accept a somewhat lower income than would otherwise be the case. If so, the foregoing assumption that the value of higher degree holders will be largely reflected in their increased salaries may be quite conservative. Furthermore, at least for private-sector employers, the willingness to pay for value received will reflect only the value received by that employer; this may approximate the value received by society as a whole but it could also underestimate it. (This point parallels the question of 'private' versus 'social' returns discussed in section 1.2.) These factors mean that our calculations will probably be underestimates of the graduates' full value. Of course, similar considerations would also apply to earlier studies [18] on first degrees.

This approach, of course, assumes that the reason for the increased earnings is almost entirely the additional education. Studies considering undergraduate education [18] 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 Highly Qualified Personnel (HQP) report of the present Review of Physics, and from recent NSERC surveys of Postgraduate Scholarship winners, this is a very good assumption. Moreover, we have no reason to believe that the economic importance of graduate degrees received by those who later cease to use their physics directly is any lower than for those who continue in mainline physics. Indeed, the HQP report of the present Review shows that almost all of those who do not use physics directly still use the skills and modes of thought learned from physics and ascribe high importance to this in doing their jobs. In any case, the calculations will use data which reflects all the responses to questionnaires, regardless of whether the respondents were still using their training directly.

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

Summary. Based on a variety of data, we conservatively estimate the additional lifetime-average salary for physics Ph.D.'s and M.Sc.'s, compared with B.Sc.'s, to be about $12K and $5K p.a.

A review of the 1995 salary survey [42] carried out by the Canadian Association of Physicists (CAP) suggests immediately that higher salaries may indeed be associated with advanced degrees. Excluding age ranges where B.Sc.'s may well still be graduate students, and adjusting for differences in the age distribution of the respondents, we calculate a difference of about $18K 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), so this data should be rather accurate. The median salary is $74K for 1995, and $75K in 1993 and 1994 [43, 44]. Statscan [45] shows an average 1990 salary, based on a 20% sample, for the 'Physicist' category (category 2113) of $51.2K. If we uplift this by the 5.6% inflation rate for 1991 and by 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, the Physicist category should contain at least a fairly large proportion (but not 100%) of non-Ph.D.'s. Thus, the salary difference of $13-18K between this group and CAP's Ph.D.'s might be an underestimate of the real difference between Ph.D.'s and B.Sc.'s.[v] 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 for higher paying jobs outside of the scientific world.[w]

There is additional Statscan data [46] on a sample 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 the difference between Ph.D. and B.Sc. salaries comes from Statscan data [45] on the 1990 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

[v] 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. The converse could happen to some extent, which could cause us to underestimate the difference between B.Sc. and Ph.D. salaries.

[w] 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 [45], and the number of individuals is only 4% of total NSE occupations.

Ph.D. is needed; both groups are national, often 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 rise to over $18K.[x]

The foregoing data are highly suggestive of a difference between B.Sc. and Ph.D. salaries in the range of $10-20K p.a. However, it would be more satisfying to have more controlled and detailed data; moreover, we shall need to know the age dependence of the salary differences. The figures have therefore been supplemented by extensive Chemical Institute of Canada (CIC) information on chemists [47] kindly provided by Ann Alper, Executive Director of CIC. We strongly suspect that this will be a reasonably accurate surrogate for physicists.

We analyzed the 1993, 1994 and 1995 CIC data (the last being the most recent available at the time) by age range and degree, and obtained the following results for 1995 as an example. Although it would not have affected the final numbers greatly, we did not use the first or last age range in the CIC data. The number of respondents in the first range (those who obtained their bachelors degree before 1956) was much too small to allow reasonable comparisons between degree types. The last range (post-1990 graduates) is inappropriate, since many of the B.Sc.'s would still be in graduate school and the graduate degree population is therefore small. Indeed, the Ph.D. salaries for even the 1986-90 cohort will likely be biased down somewhat because of post-doctoral fellows (PDF's). The first number in each of the total salary columns below is the average salary in $K, and the second number (in brackets) is the number of respondents in that category.

Table 2. Chemistry Salary / Degree Relationships 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 $74K. 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 is well under $1K. This encourages us in our belief that the two disciplines are very 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 survey 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 for physicists. We suspect that the

[x] 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, restricting the comparison to men merely leads to a difference of $18K instead of $17K (1990 dollars). Comparing for both genders but in only one Province (Ontario for example) leads to a difference of $16K. Within the overall accuracy of the discussion, these effects are not material.

remaining difference could reflect the presence of about 18% of engineers in the CIC data. While Ph.D. salaries (which are significantly weighted by often-unionized teaching positions) might be expected to be comparable between scientists and engineers, we suspect that bachelors' salaries might well be a little higher for engineers. Whatever the reason, estimates of the differences between B.Sc.'s salaries and those of more highly qualified people will apparently tend to be conservative when based on CIC data.

(iii) The CIC data show a negative difference for M.Sc.'s for the 1986-90 cohort and a slightly negative one for Ph.D.'s. This is consistent with data in the HQP study of the present Review of Physics, although we find that its negative differences partly disappear 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 'permanently' employed, one would expect B.Sc.'s to have a small advantage in this age period; this would temporarily tend to offset the advantage of a graduate degree. Also, as previously mentioned, PDF's would tend to reduce the Ph.D. average for the early years.

Random variations cause considerable year-to-year fluctuations in Table 1, particularly in the (M.Sc.-B.Sc.) data. To minimize these, 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.; inflating all these by 2.5% p.a. 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 a 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 HQP data in the present Review), 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 somewhat higher values for the (Ph.D. - B.Sc.) difference, the use of the CIC figures again seems conservative.

6.3 Discounted Value of a Career's Earnings

Summary. The average salary differentials estimated in section 6.2 are converted to lifetime totals and discounted to present values. The results are \$146K per physics Ph.D. and \$68K per M.Sc., in both cases compared with a B.Sc.

To estimate the economic value which is created when a Ph.D. or M.Sc. graduates, we must sum the annual salary differences from the previous section, 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 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 time as a graduate student is less than that of a person of similar age who is permanently 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 less to do with economic worth than with (i) the availability of money in a situation which is not a truly competitive market, and (ii) students' desire, for reasons which go beyond economics, to obtain an education. Similar comments apply to PDF's, although their lower salaries are largely included in Table 2 and will automatically be factored into our analysis.

We performed the discount calculation by summing the average 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% p.a. (section 1.5). Since the Research Grants associated with the graduate studies occur over a period of years after the students' B.Sc., the base year for discounting should be about halfway through the graduate studies. For those who stop their education after the M.Sc., we therefore started discounting 1.5 years after the B.Sc., while for Ph.D.'s we started after three years. 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% p.a. 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, each age range should be weighted equally, except perhaps for some small allowance for mortality effects. In fact, we have not used CIC's earliest time period (B.Sc. earlier than 1956) in this analysis, mainly because the numbers reporting in all categories were small. This cuts off the comparison when people are roughly 60, and so (apart from preserving the integrity of the data) this may 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 $146K and $68K respectively.

6.4 Ph.D. and M.Sc. Generation

Summary. The numbers of physics Ph.D.'s and M.Sc.'s who are produced in Canada per year and who stay here are estimated to be 91 and 100 respectively. The M.Sc. numbers do not include those who go on to become Ph.D.'s. Multiplying these numbers by the per-person lifetime salary differentials in section 6.3 yields a total of $13.3M for Ph.D.'s produced in any given year and $6.8M for M.Sc.'s.

Rostoker and Tooley [48] report 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 by CAP [49] of physics Ph.D.'s granted in the preceding year (1996); this lists 136 people. Since full details were required for inclusion in this list, we would expect it to omit a few people. The CAP list showed 150 people in 1995 [50]. In 1992-94 [51], it showed 101-128 (compared with the Rostoker/Tooley estimate of about 150 [48]), confirming that it tends to underestimate.

NSERC [52], however, reports slightly lower Statscan numbers. For 1993-95, these average 134 Ph.D.'s and 229 M.Sc.'s. NSERC [52] suggests that this may reflect the inclusion of biophysics and geophysics in the study published by CAP. To correct for this, we reviewed the detailed CAP listings of Ph.D.'s granted in 1995 and 1996 [49, 50] and identified all those that appeared to be outside the areas covered by this Review. We excluded Ph.D.'s which appeared to be in astronomy, geophysics, biophysics, atmospheric physics or medical physics; this is conservative, since some of this work could easily be supported by the GSCs considered in the present study. We found that about 13% of the theses fell into these categories. Assuming the same proportion applies to M.Sc.'s, the 150 and 275 CAP Ph.D. and M.Sc. numbers in the previous paragraph are reduced to 130 and 240. These are close to the Statscan numbers and we use them for the following calculations.

In order not to double-count, we must also subtract from the M.Sc. numbers those who go on to become Ph.D.'s. We are told [53] that this is likely 80-85% of the numbers of Ph.D.'s. We therefore subtract 107 from the M.Sc. numbers to arrive at an estimate of those who stop at that level. This leaves 133 M.Sc.'s per year.

Since we are calculating incremental value to Canada from later employment here, we must also subtract the proportion who leave Canada permanently after graduation.[y] On this, there appears [52] to be little firm data, but we can make a rough estimate from various sources. A review of CAP's detailed Ph.D. listings for 1995 and 1996 [49,

[y] The 'export' created by universities in teaching the approximately 27% of Physics and Astronomy M.Sc. and Ph.D. recipients who are foreign [52] will be considered in section 7.

50] shows that, of those graduates who were ‘permanently’ employed soon after graduation, about 26% had left Canada. If we include all graduates with any known position (including PDF’s), the proportion rises to 41% (22% of them in the U.S.). Presumably, many but not all PDF’s will return, so we might reasonably assume that the numbers staying abroad will be somewhere between 26 and 41%. This is consistent with the proportion of all permanently employed Ph.D.’s in our HQP Study who did Canadian Ph.D.’s and then left (about 30%). The equivalent number for M.Sc.’s (based on our HQP data, which is the only data of which we are aware) is about 25%. These emigration numbers are slightly more pessimistic than SFU data [54] for all their physics graduate students since 1979, which shows 47/193 working abroad (including PDF's), or about 25%. They are also more pessimistic than recent Sherbrooke physics experience [55] (about 20% for both degrees). They are much more pessimistic than the University of Ottawa physics experience [56], where in the recent past very few graduate students left Canada at the end of their studies. Nevertheless, we shall assume conservatively that 30% of Ph.D.'s and 25% of M.Sc.’s leave and stay abroad. These numbers include foreign students and are similar to the proportion of such students in the graduate student population: apparently, the number of foreign students who stay roughly offsets the number of Canadians leaving.

We thus end-up with about 91 Ph.D.’s who stay, and about 100 M.Sc.’s.[z] Simply multiplying these numbers by the discounted dollar estimates in the previous section gives $13.3M p.a. for Ph.D.’s and $6.8M for M.Sc.’s, for a total of $20M p.a. This does not appear to be the end of the story, however.

6.5 Calculation of Actual Impact

Summary. At least for Ph.D.’s and M.Sc.’s going into industry (and possibly for other sectors) there appears to be a kind of ‘social’ multiplier to be applied to the numbers in section 6.4. This reflects the fact that if an individual is to ‘pay for’ herself from the employer’s standpoint, she must create incremental revenues of several times her salary. Conservatively applying such a multiplier only to industrial employees increases the total economic value of one-year’s crop of Ph.D. and M.Sc. graduates to $25M and $16M respectively. Adding the cash spent in Canada by foreign graduate students (which is calculated in section 7) increases the grand total by $3M to $44M.

Calculations analogous to the preceding subsections have been made for undergraduates in several other studies [18]. 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 rather self-contained U.S. economy, we believe 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 ultimately maintain or slightly increase its profit by doing so. But if the company does indeed eventually achieve higher revenues as a result of this hiring decision than it would have achieved otherwise (typically by establishing new markets or protecting existing ones), its associated incremental profits will naturally not equal 100% of the additional revenues. Indeed, incremental profits (before taxes) would rarely exceed 25% of the related revenues and would very often be much lower. Thus, in order to pay out $X in additional salary to a Ph.D. (instead of a B.Sc.) and not end up losing money, the company must expect that its revenues will increase (or be protected

[z] 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.

from decreasing) as a result by at least about $4X.[aa] But, as explained in section 1.1, it is revenues, not incremental profits, which are the proper measure in comparing impacts against government expenditures. Recall, once more, that this might well not be true in the U.S.

To give a simplistic example, consider a company that hires a Ph.D. instead of a B.Sc. and pays him $12K p.a. more than the B.Sc. would have received. If the company's revenues eventually increase by $50K p.a. because of an advance stemming from this hiring decision, and if its incremental profit margins are 25%, it will increase its profit by $12.5K p.a. (25% of $50K). Thus (neglecting the time value of money, section 1.5), it could justify the additional $12K salary. However, the primary impact on the Canadian economy (assuming incrementality as usual) is more like $50K. As usual, this is because most of the additional $38K is probably spent on other Canadian salaries, purchases, etc. <u>What we have in essence is a kind of social return, and like other social returns this multiplies the impacts beyond the 'private' returns ($12.5K in the above example) received by the company</u>. It is important to understand that this multiplier has nothing 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, nor with the conventional social returns of section 1.2.

Thus, we have a multiplier of at least 4 (the inverse of a 25% profit margin) to be applied to the figures in section 6.4 in order to arrive at the primary economic impact, at least for graduates going into industry

It is harder to determine an appropriate multiplier, if any, for people entering other sectors. While we believe that arguments can be made that a comparable multiplier should be applied to other employment sectors, the arguments are long and uncertain. Conservatively, therefore, we shall apply a multiplier only to the industrial employees.[bb]

We therefore need to determine what proportion of physics M.Sc.'s and Ph.D.'s go into industry. We have found little published data on this point. However, data obtained for the HQP Study of the Review of Physics indicates that of those (fairly recent) Ph.D. graduates who are now 'permanently' employed in Canada (in principle not including PDF's) approximately 30% are in industry, 51% in education, 15% in government, and 4% in 'other'. For M.Sc.'s permanently employed in Canada, the numbers are 43%, 29%, 16%, and 12%.

[aa] That is, by $X divided by 25%. The payback may be delayed, of course, perhaps by many years. But on a discounted cash flow basis (section 1.5), the company cannot be acting in its economic interests unless it believes that it will receive a payback of this magnitude.

[bb] This, of course, is not intended to imply that the industrial employees are more valuable than the others, merely that it is harder to analyze other employment situations in an economic sense.

We thus apply a 4x multiplier to the industrial percentages (30% and 43%) and conservatively leave the other impacts unchanged.[cc] The result so obtained is a total value of $25.3M for Ph.D.'s and $15.5M p.a. for M.Sc.'s, or in round terms a grand total of $41M p.a. In addition, section 7 estimates an impact of about $3M for the Canadian spending by foreign graduate students trained here who do not remain in Canada. While this is easier to discuss in the following section, it seems logical to add it to the above total, for a final estimate of $44M.[dd] [ee]

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 could significantly help justifications for increased NSERC spending.

> Recommendation 4. 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 FOREIGN STUDENTS

Summary. If NSERC research did not exist, fewer foreign undergraduates would come to Canada and more Canadian undergraduates would study abroad. Because NSERC research does exist, the reverse occurs and this constitutes an export (and import substitution) related to the amounts spent by the students involved. The total impact is estimated as $11M p.a. Foreign graduate students add $3M to this, which has been added to the section 6 totals.

Canadian universities are rightly regarded as excellent on an international scale, and therefore they attract a large number of foreign 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, it seems reasonable to assume that the money for these activities comes largely from abroad. 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 scientific research to exist.

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

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

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[cc] 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 [57] 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.

[dd] Of course, general Provincial government university spending (estimated [18] 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 plus the universities' infrastructure spending on physics research (likely, section 1.6, of order $36M per year), then much of the incremental university cost of physics graduate degrees would already be counted: 370 degrees/year x $82K is, in fact, about $30M. In addition, we have already pointed out (section 1.6) that NSERC spending on Scholarships is also a necessary condition for the economic impacts of graduate student training; however, this spending is rather small compared with Research Grants.

[ee] There is some possibility of double-counting between section 3 (spin-off companies) and this section. However, we assume that the range of companies in which Ph.D. physicists work is much larger than university spin-offs, so that the extent of double-counting should be small.

(ii) the prestige of Canadian universities, at least in the sciences, would drop sufficiently that the number of foreign undergraduate science students would drop to low levels,

(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 via effect (iii). We now attempt a rough estimate of the impact of these effects.

According to NSERC figures for 1991-95 [52], about 4% of Physics and Astronomy undergraduate enrollment consists of foreign students. We make the following additional assumptions: (a) there are about 13 undergraduates for each faculty member, based on an all-discipline AUCC number [46] [ff], (c) we consider all Canadian physics faculty (about 800, excluding Astronomy[gg]), (d) the total spending by an foreign student is probably about $18K per year, including tuition, of which we assume that 75% comes from foreign sources.[hh] The total export is then the product of these factors, or about $6M p.a.

To estimate the import substitution (effect (iii)), we assume conservatively that the number of Canadian undergraduates going abroad would at least double if the reputation of Canadian universities dropped substantially because of a cessation of research. According to NSERC [52], 27,437 Canadians were studying at foreign universities in 1993, 82.6% of them in the U.S. In the U.S., about 58% of these were undergraduates. Assuming this percentage is roughly true for other destinations, this implies 15,913 undergraduates. According to AUCC [46], the total number of bachelors-level students at Canadian universities is about 454,000, excluding Visa students. This implies that about 3.5% of Canadian undergraduates are studying at foreign institutions. Assuming that (i) this percentage holds true for science, (ii) the present number of Canadian physics undergraduates is 13 x 800 as before, and (iii) per-student spending abroad is similar to that of foreign students in Canada (probably a conservative assumption), we estimate that a doubling of the 3.5% will cause an additional outflow of Canadian funds of about $5M p.a. Note that this does not take into account the value presently received by those Canadian undergraduates who would nonetheless stay in these dire circumstances; this is correct, since this by definition does not depend on NSERC research. The total net impact for undergraduates is thus about $6M + $5M = $11M.

Finally, we turn to the export associated with foreign <u>graduate</u> students. Rather than using the number of degrees and estimating the average number of years for a degree, so as to arrive at the total number of students at any one time, we use direct data on the numbers of physics M.Sc. and Ph.D. students. These are reported [48] as 780 and 967 for 1993-94. As in section 6.4, we subtract 13% to allow for studies in the areas of astronomy, atmospheric physics, geophysics, biophysics and medical physics. Assuming 27% of the remaining students are foreign, again

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[ff] We also found science-faculty numbers averaging in the same region at three university web sites. We cannot simply use the absolute number of undergraduates in reference 52, since this often does not include physics students in their early years, nor non-physics students taking courses in physics.

[gg] 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). These were 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 or (b) all university degrees granted; these two calculations give 750 and 830 faculty respectively. The calculation may be somewhat high for Quebec, because of the CEGEP system, but is sufficiently accurate for our purposes. This estimate of about 800 faculty members is confirmed by NSERC [52], which indicates 885 faculty members in Physics <u>and Astronomy</u>.

[hh] These numbers, which seem intuitively reasonable, are based on a Vancouver Board of Trade Study in 1986 [58], which found that foreign students spent $10K p.a. in Canada, 75% of it originating from outside Canada. Since that time, foreign student undergraduate fees have risen rapidly; at the University of Western Ontario, for example, they were $4,851 in the faculty of science in 1988 [59] and $10,457 in 1995/96 [60]. Even if they rose only in line with general inflation in 1986/88, the total increase is 134%. If we assume that students' remaining expenses rose in line with general inflation (38% to June, 1997 [30]), these numbers imply that the $10K will have increased to just over $18K.

as in section 6.4, gives us 183 foreign M.Sc. students and 227 foreign Ph.D. students. NSERC [52], based on Statscan data, gives averages of 116 and 216. The Ph.D. numbers agree well, but there is a considerable difference for M.Sc.'s, the reasons for which do not appear to be understood [52]. For our present purposes, we shall not incur significant errors by taking the averages of the two sets of data. We then have about 370 foreign students in total[ii]. These numbers, of course, will include those who may not ever graduate, which is correct for the present calculation. We might guess that the total amount spent, including tuition, is about $18K p.a. like undergraduates. However, 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 370 x $9K, or about $3M p.a. This amount has already been added to the estimates in section 6.

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 5. NSERC should initiate a proper study of the extent to which NSERC research in all disciplines creates economic impacts related to spending by foreign students in Canada and reduced spending by Canadians studying abroad.

8. OTHER IMPACTS

There are a few other impacts that should be considered briefly.

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

Summary. The impacts of targeted programs are partially dependent on the ongoing support provided by the Research Grants program. We have not included these impacts in this study, since we have found little data on the impacts and they are more directly attributable to the targeted programs.

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 (NCE) 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 partly 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 ([61], for example). However, we understand [62] 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 NCE's 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 [63] of physics researchers involved in University-Industry awards initially approved in the years 1988-94. We asked them for specific examples of commercialized work, together with

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[ii] Where a foreign student stays in Canada after graduation, section 6 already includes the value of her subsequent career. However, the inflow of foreign money for her training period seems to be a separate impact.

quantitative data. Unfortunately, we were able to obtain very little information[jj], and again must suspect that little quantitative study has been done.

8.2 The Value of Non-Government Contracts and Foreign Grants

Summary. The export represented by foreign grants received by NSERC-supported physics researchers, and related import substitutions, give a total impact of about $2M p.a.

Many researchers who are supported, often primarily, by NSERC Research Grants also obtain research contracts from non-government or foreign sources, such as industrial companies. If these are from non-Canadian sources, the associated revenue (which is spent primarily in Canada) is 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.

To obtain a rough estimate of this effect, we examined the 55 recent NSERC Research Grant Application forms obtained by the Condensed Matter SubCommittee of the present Review after clearances from the corresponding grantholders. We noted the size of the existing NSERC Research Grant, and also the magnitude of any grants which were held in the year of NSERC Grant renewal and which fell into the categories mentioned. We excluded all government and other general grants (from NSERC, CIAR, FCAR, NCE's, university sources, etc.). We also did not consider industrial support via a Research Partnerships or similar grant, although a case could be made that some of these might fall into the category considered here. Most of the remaining items were contracts from Canadian or U.S. industry, or foreign fellowships. We did include two medium-sized contracts from Canadian government sources (CSA and CANMET), because these appeared to be for specific work which would otherwise have been sourced elsewhere, rather than general grants.

These forms showed returning total grants of $1.74M, Canadian contracts of $276K and foreign-source income of $56K (all but $12K of it from foreign fellowships and the like). To calculate an impact for all NSERC-supported physics researchers, we assume that (i) half of the Canadian contracts would have gone abroad in the absence of such researchers, (ii) this is a representative sample for the rest of the Condensed Matter and General Physics population, so that we can gross up the numbers to the relevant research grants totals, (iii) it is a representative sample for SubAtomic and Space Physics only for foreign fellowships and the like, i.e. we conservatively neglect any industrial contracts received by researchers in these GSCs. Since we are normalizing via the magnitude of the returning grants, the gross-up is done to the total GSC 'operating' grants; for SubAtomic, this was taken as 70% of the envelope.

The total impact is thus calculated as $0.9M for half the Canadian contracts, and $0.7M for foreign income, yielding a total of $1.6M, which we round to $2M.

[jj] However, we would like to acknowledge Bret Heinrich of SFU, who (with Gordon Haid at 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.

8.3 International Conferences in Canada

Summary. Spending by foreign attendees of major physics conferences in Canada adds a roughly $1M impact which would not occur without NSERC Research Grants.

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.[kk] This is not a very large effect, so our discussion will be limited to a rough estimate.

Two of the Review SubCommittee Chairs kindly provided rough estimates of the situation in their subdisciplines. In General Physics [64], one major conference was estimated every second year. Excluding travel support for foreign speakers, the conference fee spent in Canada was estimated as about $400. Assuming 500 participants (about 400 from outside Canada), a 5-day conference, and accommodation and food costs per person of respectively $350 and $250, we estimate the total spending by foreigners as about 400 x $(400 + 350 + 250), or $400K. If this happens every second year, we have $200K p.a. This might increase [64] to $250K if we include other foreign visitors with their own sources of funding.

In Condensed Matter [65], again we assume one major conference every second year, with 400 visiting attendees. Assuming a 5-day conference, a $250 conference fee, and $150 spent per person per day, we again estimate $200K per year.

To allow for SubAtomic and Space Physics, for which we have no specific estimates, we simply gross-up these numbers by the ratio of total physics Research Grants spending (roughly $36M p.a.) to that for Condensed Matter and General Physics ($15M). We arrive at a final estimate of $1.1M, or in round terms $1M.

8.4 Faculty Consulting

Summary. Little information appears to be available on the impact of physics faculty consulting.

A study of the economic benefits accruing from the University of Calgary [66] 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 did. On the other hand, the consulting income reported to the annual CAP salary survey [42-44] is rather small (a median of $7.6K each for 26 people in 1995, and comparable amounts in 1993 and 1994). This may imply 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.

[kk] 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.

9. CONCLUSIONS

We have attempted to give a first, rough but conservative, estimate of some short- to medium-term primary economic impacts which would not occur without the $36M p.a. NSERC physics Research Grants program. It appears that these impacts (shown in Table 3) can be directly compared with the grants, in the sense that they represent the expenditures which would be necessary if the NSERC program did not exist and governments wished to generate a similar economic impact by injecting cash directly into the economy. The impacts in Table 3 give rise to consumer multiplier effects, similar to (but probably somewhat larger than) the multipliers which would occur if the government injected the cash directly. The total economic impact is therefore probably 3 to 5 times higher than the numbers shown.

Table 3. Summary of Primary Economic Activity Estimates *

Impact	Primary Economic Activity Generated p.a. Does not include consumer multiplier effects**	Comments
Activity directly generated by initial expenditure	$36M	Initial expenditure creates at least as much direct Canadian economic activity as most other government expenditures of this size.
Spin-Off Companies	$222M	Does not include the WWW, which spun-off from international SubAtomic physics.
Technology Licensing	$7-12M	
Medium-Term Impacts on Existing Companies ("Mansfield" effects)	?	Probably large. Needs a major NSERC study.
Economic Present-Value of Post-Graduate Training	$44M	Includes $3M estimated Canadian expenditures by foreign graduate students.
Revenues Generated by Foreign Undergraduates Taught by Canadian Physics Departments	$11M	Very approximate. Assumes that, absent NSERC research, few foreigners would study science in Canada and more Canadians would study abroad.
Value of Non-Gov't Contracts and Foreign Grants which Depend on Underlying NSERC-Supported Research	$2M	
Amounts Spent by International Conference Attendees	$1M	
TOTAL	**> $323M**	

* **Does not include long-term impacts of international physics, second order impacts e.g. second-generation spin-off companies or most other 'social returns', the value of faculty consulting, or the impact of the Research Grants program on researchers' 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 allow 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. For physics as a whole, the share of revenues is significantly higher than the share of Research Grants (18.1% versus 14.7%).

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

- The very large impacts of international physics in enabling major inventions like the transistor, the laser, NMR, the World Wide Web, etc. It could be argued that these are not incremental effects of NSERC work, because to some extent, 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 was heavily involved in the research stages, compared with those where our involvement was less significant.

- ‘Social’ Returns. 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. This is so because the improved products and processes reduce the costs to consumers and improve the economic performance of companies that 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 Canadian impacts of Canadian research, since (given the international markets of high-tech companies) most of them would presumably accrue to non-Canadian companies and residents; meanwhile, the Canadian impact of non-Canadian innovations is not a direct result of NSERC.

- Second-Generation Spin-Off Companies. 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-generation spin-off. One of the companies in our spin-off study, for example, has spawned approximately 20 additional companies, and their total revenues exceed that of the parent company.

- Mansfield Effects. 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.

- Research Partnerships, NCE’s, Targeted Provincial Programs, etc. 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 a total present value of over 9 times the associated investment. Including consumer multiplier effects, the total activity generated is in the $1000-1600M p.a. range! 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, an outstanding investment.

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