How University Research Can Boost Economic Growth

by
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Introduction

Technological progress is the ultimate source of long-run economic growth. It is what makes the average Canadian three times as rich today as fifty years ago. We are richer not because we produce more typewriters, black and white television sets and rotary-dial telephones, using the same processes as fifty years ago, but because we have invented new products and processes. We now have jet airliners, high-definition televisions, computers and automatic teller machines; we have discovered new production processes, like lean manufacturing techniques and just-in-time inventory management that produce and deliver goods more efficiently than before; and we have made medical advances like laser surgery, organ transplants and angioplasty that enable us to live longer and healthier lives.

The source of these technological innovations is research and development (R&D), most of which takes place in the private sector of the economy. But business R&D is not the whole story. University research also plays an important part in the innovation process, through a variety of channels. For example, researchers at universities were the first to develop a great deal of medical, engineering and computer technology. In addition, many scientific discoveries that originate in basic university research ultimately find their way into new technologies, as when breakthroughs in biology lead to new methods of genetic engineering, or when advances in solid-state physics make it possible to design faster processors for computers.

Indeed, university research is at least as important as private R&D in many sectors. According to Cockburn and Henderson (2000) hardly any of the major drugs that have come onto the market since 1965 have resulted from private research alone; university researchers undertook most of the basic research, discovered many of the new molecules, and conducted many of the clinical trials. Likewise, teaching hospitals connected to universities are the source of most new surgical procedures. University research was also the source of almost all the basic building blocks of our information age, from the basic architecture of digital computers through the development of the underlying protocols of the internet. And many of the firms that pioneered modern information technology were spinoffs from universities like MIT and Stanford. These firms combined to create networks, in Route 128 and Silicon Valley, whose

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innovations are responsible for much of the productivity growth we have experienced in North America in the past quarter century.[2]

This *Commentary* analyzes the process of technology transfer - the process through which university research contributes to technological progress and economic growth - from the viewpoint of the modern theory of innovation-based economic growth and in the light of academic research on the topic of technological change. It shows that Canadian universities lag behind their US counterparts in generating technology transfer, and suggests measures that might be taken, by businesses, universities, provincial governments and federal granting agencies, so as increase contribution that university research makes to Canadian economic growth.

More specifically, the *Commentary* suggests that Canadian businesses should be devote more resources to research and development so as to play their role in the technology transfer process to the extent that businesses do in the United States, that federal granting agencies should set a higher priority to creating a research environment that will attract the very best scientists and engineers to our work in Canadian universities, that universities and provincial governments should provide university researchers with access to a broader range of commercial and legal expertise in their interactions with business, and that the federal government should (a) implement the recommendation of the Jenkins report to the effect that National Research Council Institutes be reoriented towards fostering university/industry collaboration, (b) create an online repository providing open access to all federally funded research papers and (c) develop a series of standard protocols to govern the sharing of commercialization revenues between universities, researchers and their business partners.

2 University research in Canada

Canada spends billions of dollars every year on university research. In 2010, for example, our expenditure on higher education R&D was 11.2 billion dollars, which was 38 percent of total Canadian R&D expenditure, or 0.7 percent of GDP. Most of this expenditure was publicly funded, either directly in the form of government sponsorship of research, or indirectly through grants to faculty research or support coming through the general funding of publicly supported universities.[3]

[2] Technology spillovers from academic research have been documented by many studies, including Jaffe, 1989; Furman and MacGarvie, 2007; and Hausman, 2011. Tecu (2011) finds no effect of the presence of proximity to a research university on patenting activity by business establishments in the US chemical industry, but observes that this could be because the kind of research collaboration engaged in by establishments close to universities is likely to be basic research that does not produce an immediate payoff in the form of patenting.

[3] In 2010, 82 percent of the cost of higher education R&D was funded by the government sector, 8 percent by private for-profit business enterprises, and the rest by non-profit private organizations and foreign sources.

Over the past three decades, these expenditures have grown more than twice as fast as the overall economy. The percentage of Canadian GDP spent on research in higher education has grown from 1/3 of one percent of GDP in 1981 to over two thirds in 2010 (Figure 1). The rapid growth starting in the late 1980s reflects to a large extent increased federal funding. In 1989 the federal government adopted a science and technology policy for the first time, and began focusing on universities rather than government labs in the National Research Council (NRC) as a locus for scientific research. Around that time the federal government also started the Canada Research Chairs program to support professors whose research is highly ranked, and also started funding Networks of Centres of Excellence. The Centres of Excellence in Commercialization and Research (CECR) program was started in 2007.

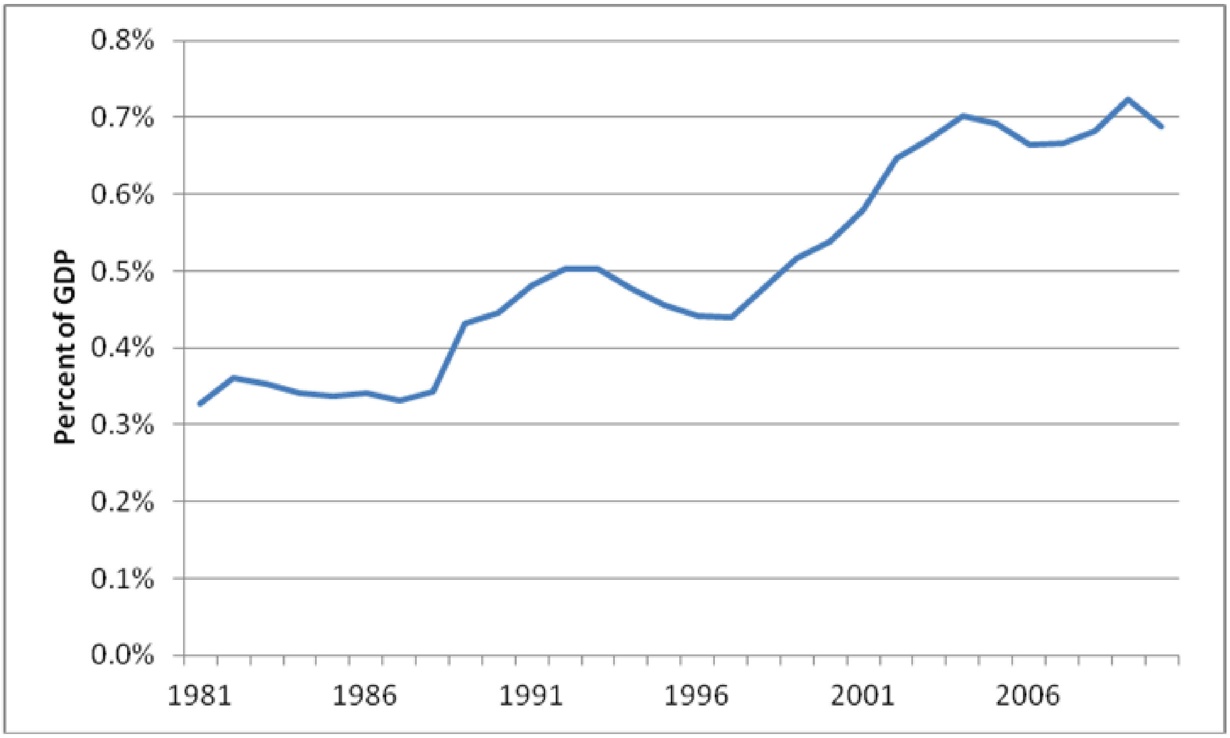

Figure 1: **HERD as percent of GDP**

About 30 percent of the public funding of university research is channelled through three separate granting agencies, namely the National Sciences and Engineering Research Council (NSERC), the Canadian Institutes for Health Research (CIHR) and the Social Sciences and Humanities Research Council (SSHRC).[4] Most of these agencies' budgets go towards funding individual and group research projects by university faculty, although a significant amount of it also goes to supporting Canada Research Chairs, Networks of Centres of Excellence and Centres for Excellence in Commercialization of Research.

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[4] A fourth granting agency, the Canada Council, funds artistic works.

The most highly rated Canadian universities are all engaged in significant amounts of research. All of them have a technology transfer office (TTO) that provides assistance for faculty members seeking to partner with private business in their research, to get funding for their research, to gain intellectual property (IP) protection for discoveries coming from their research, and to start up businesses based on technologies that they have developed. TTOs help to decide which discoveries are worth patenting and then assist in the filing of patents and/or copyrights. They actively seek out industrial partners interested in engaging in joint ventures or strategic partnerships with university research teams. They also seek out businesses that might be interested in licensing technologies developed in the university, with a view to turning the technology into a commercially viable product, and seek out businesses that need the expertise or equipment available in a research university in order to solve technological problems that they have encountered.

The Evidence on Technology Transfer

Since 1991 the Association of University Technology Managers has conducted an annual survey of university TTOs in Canada in the United States. The results of these surveys show a rapid increase in the inputs to university research in Canada, as measured by total R&D expenditure and by the number of university personnel engaged in licensing IP. In the 20 years from 1991 to 2010, the average research expenditure[5] of Canadian universities responding to the AUTM survey has almost doubled and the average number of licensing personnel has gone from zero to 5.4.

According to this same survey, the measurable output of research by the average university has also increased since 1991. The average number of inventions and discoveries has increased by 70 percent (Figure 2a), the average number of patents applied for has gone from 6.4 to 24.4 and the average number of patents issued to the university by the US patent office has gone from zero to 8.3 (Figure 2b). Similarly, the average number of licences executed in the year has gone from less than 5 to 14, income from licensed IP (adjusted for inflation) has more than doubled, and the number of start-up companies that have been spun off from research in the average reporting university in the year has gone from zero to 1.3.

[5] These research expenditures are adjusted for inflation, using the Canadian GDP deflator.

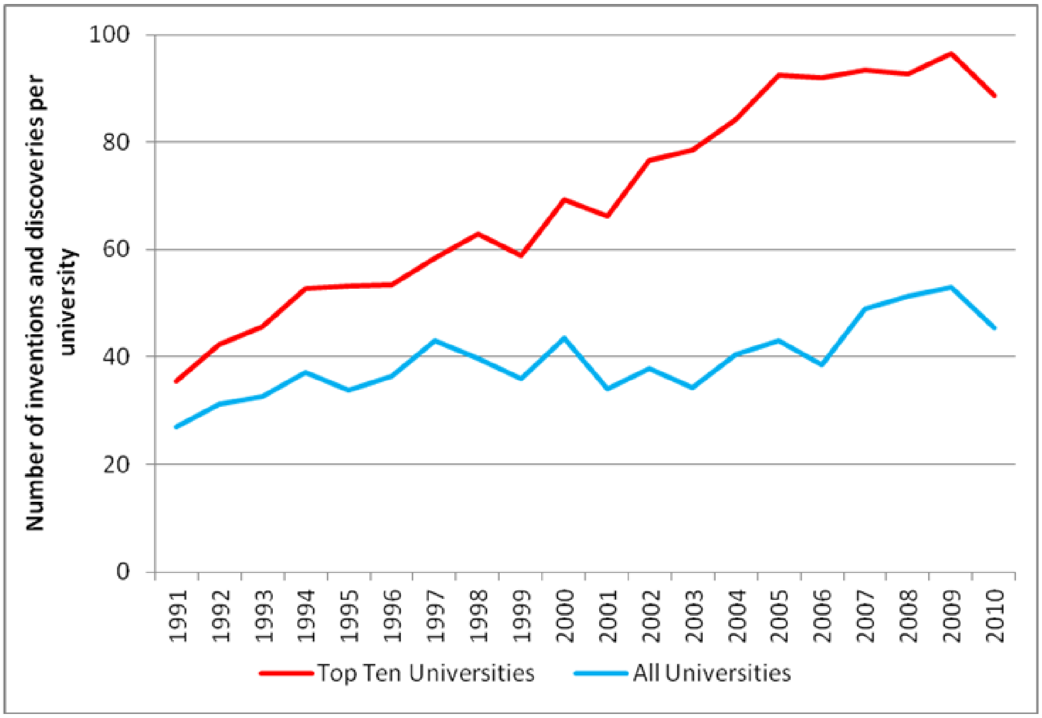

Figure 2a: Inventions per University, Canada 1991-2010

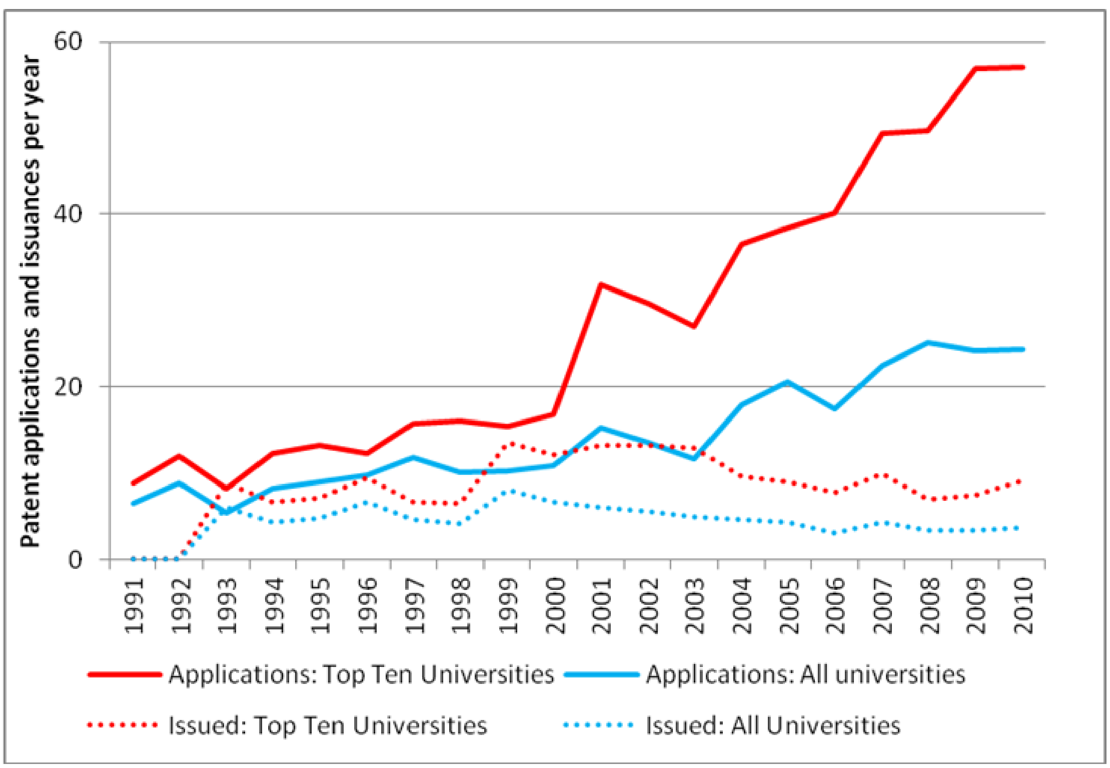

Figure 2b: Patents Applied for and Issued, Canada 1991-2010

The universities that produce the most technology transfer tend to be those that are most highly rated on overall academic grounds. Table 1 below shows that the average top ten university[6] performed better in every one of the six categories of research output on average over the period (and also experienced more rapid growth of output in all categories) as compared with the overall Canadian average. Moreover, within the top ten, average output over the 20 year period is highly correlated with the university's rank, in all but one category (number of licenses executed, which would also be highly correlated without the McMaster outlier).

Table 1

	Rank	Number of licenses Executed	Number of inventions and discoveries	Number of patents applied for	Number of US patents issued	Number of startups	Income from licensed IP (adjusted for inflation)
McGill	1	26.3	102.5	56.3	16.3	2.9	17.5
Toronto	2	26.4	126.8	29.4	7.9	5.7	24.5
UBC	3	31.3	126.2	56.3	19.4	4.9	58.3
Alberta	4	19.8	68.4	27.3	9.5	4.7	20.8
Montreal	5	23.6	62.9	47.1	7.4	3.8	9.8
Waterloo	6	14.6	10.6	6.8	3.7	2.2	12.3
Queens	7	8.2	46.8	13.8	9.2	1.8	22.6
McMaster	8	72.8	46.3	20.4	3.4	0.4	8.6
Calgary	9	28.2	81.3	24.3	8.1	1.3	33.8
Western	10	15.6	45.6	15.5	4.0	1.7	12.4
Top 10 average		25.3	72.0	29.0	8.9	3.0	22.9
Overall average		14.6	42.6	17.0	4.6	1.7	14.3
Correlation with rank (within top 10)		0.1	-0.7	-0.7	-0.7	-0.8	-0.3
US top 10 average		54.4	227.1	147.3	59.0	6.8	244.4
US/Can top 10 per constant research dollar		0.63	1.07	1.77	1.76	0.54	8.58

Comparison with US universities

A number of commentators[7] have noted that Canadian universities lag behind their US counterparts in generating technology transfer. This is evident from the second to last row of the above table, which shows that the average performance across the top 10 US universities was significantly better than across the top 10 Canadian universities in all categories. Indeed, only one Canadian university (McMaster) outperformed the average of top 10 US universities, and in only one category (number of licenses executed).

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[6]According to the World University Rankings of the Times Higher Educational in 2009 https://www.timeshighereducation.co.uk.

[7] Agrawal (2008), OECD (2012).

One reason for this discrepancy between the best Canadian and US universities is that the best US universities tend to be more highly ranked. As Agrawal (2008) notes, businesses looking to collaborate with academics look to the very best universities, most of which are located in the US rather than in Canada. Although Canadian university research tends to be well cited,[8] the most highly ranked of Canadian universities only placed 18th in the World University Rankings, and only 3 of them placed in the top 50, whereas 12 US universities rated higher than any Canadian university and 18 of them placed in the top 50.

It is also true that the best Canadian universities spend less than a third as much on research and development as do their US counterparts. More specifically, if we normalize across countries and years by measuring each university's research expenditures in 2002 Canadian dollars, the average research expenditure over this 20 year period among top 10 Canadian universities was only 2 million dollars, versus an average across top 10 US universities of 6.5 million dollars. At first glance it would appear that this factor alone accounts for most of the discrepancy in technology transfer outcomes, as shown in the last row of the above table, which reports the ratio of the average top 10 US outcome per constant research dollar to the average top 10 Canadian outcome per constant research dollar. The only category in which the best US universities dramatically outperform the best Canadian universities per research dollar is in licensing income. However, this comparison is misleading. Research dollars constitute just one of many inputs into the production of technology transfer. The fact that US universities can achieve roughly the same output per research dollar even though they are spending more of those dollars is an indication that they are more productive in generating those outcomes; otherwise they would be experiencing diminishing returns to the single input of research dollars.[9]

There are other factors that could account for this Canada-US productivity gap. TTOs are generally more experienced in the United States than Canada; many U.S. universities started organizing TTOs in the early 1980s, whereas in Canada they started being organized in the 1990s. It has also been said that

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[8] According to the Times Higher Education World University Rankings 2012-2013: http://www.timeshighereducation.co.uk/world-university-rankings/2012-13/world-ranking, the Canadian universities in the top 200 of the world rankings all score the same or better on their citation ranking compared to their overall ranking, suggesting that Canadian universities over-perform in international rankings on the citation score. According to the Council of Canadian Academies (2012) Canadian universities as a whole rank 6th in the world in terms of the quality of their research, as measured by average research citations; and according to a survey that the Council conducted among over 5000 leading international sciences, the quality of Canada's science and technology sectors ranks 4th in the world.

[9] This is the conclusion drawn by Agrawal's (2008) econometric study of university productivity in generating technology transfer.

generally speaking Canadian universities have a less entrepreneurial culture than their US counterparts (Agrawal, 1998). Venture Capital is more highly developed in the United States, which makes it easier to spin off new companies and otherwise to commercialize research than in Canada.

Most importantly, in order for us fully to realize the potential benefits from university-academia interactions it takes not just university research but also business research. Figure 3 below shows that while Canadian universities spend more on research, relative to GDP, than their US counterparts, Canadian businesses spend only half as much as their US counterparts. The story told by Figure 3 (based on data from the OECD) is particularly important. Just as labor productivity depends not just on the quality and motivation of workers but also on the quality of the capital and technology they have been assigned to work with, so too the productivity of universities in generating technology transfer depends not just on their own efforts but also on that of their potential business partners. It is doubtful that Canada will be able to close the productivity gap with the US in technology transfer until businesses start to play their part instead of relying on universities to do more than their share.

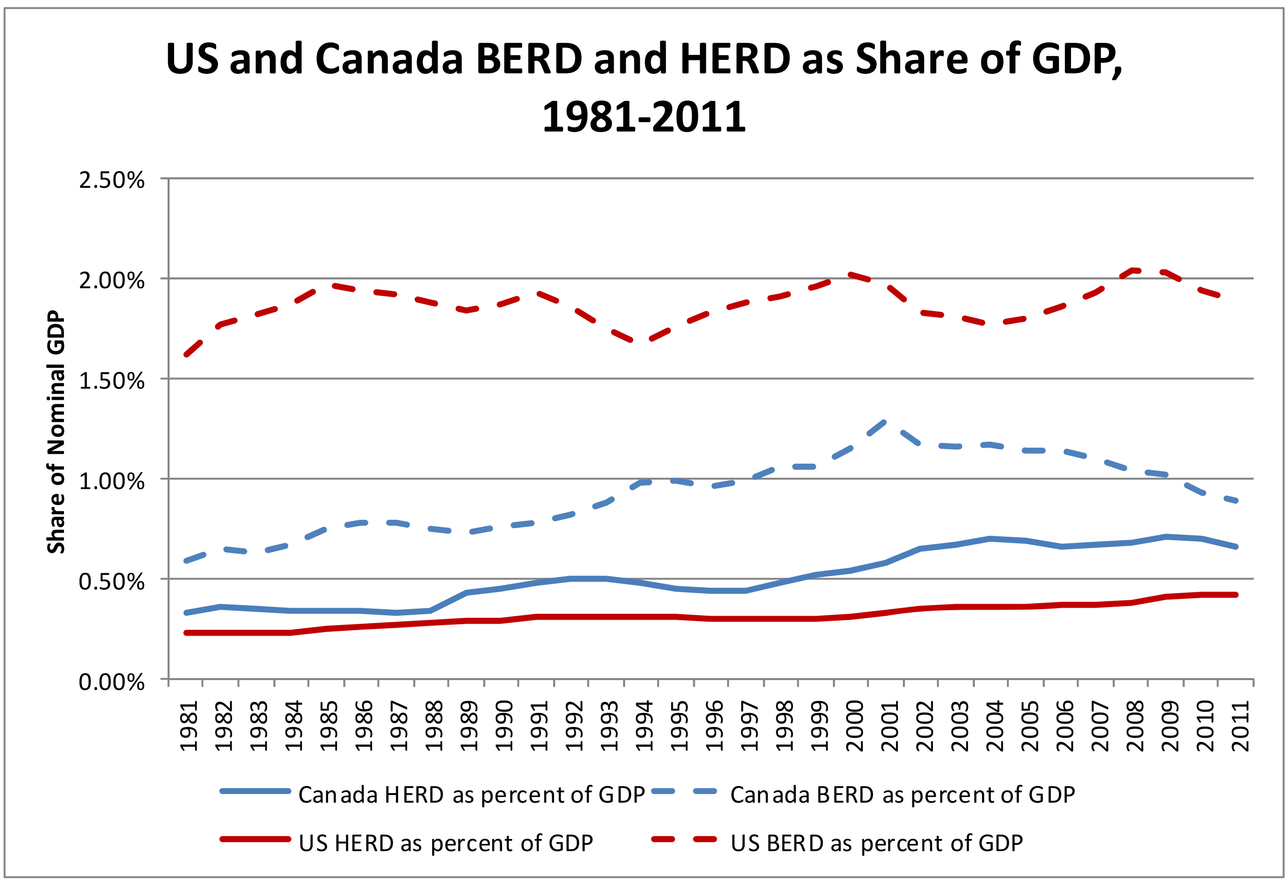

FIGURE 3

3 Rewarding technological progress

Intellectual property consists of tangible representation of ideas, discoveries, inventions, designs, formulas, symbols and other creations of the mind. It is a kind of capital good. Like a machine, it can be produced at a cost, it can be bought and sold, and it can be used as an input to a productive process. But it has one important feature that distinguishes it from other kinds of capital, namely that it is a non-rival good.[10] That is, any number of people can use the good any number of times without having to pay the cost of producing it.

Consider, for example, a process innovation that consists of a new method for producing glass bottles faster and with less breakage. The cost of producing this innovation consists of the wages and salaries of the R&D personnel that the company employs to come up with the idea and to refine it to the point where it became workable, along with the cost of whatever equipment and raw materials were used up in the process. But once it has been developed, the idea can be used over and over without anyone having to pay that cost again. In contrast, the machines and other inputs used in the factory are rival goods. If a company doubles its bottle production by opening an additional factory, then it will have to pay for twice as many machines and other inputs, but it will not have to pay any more for the discovering the new method that will be used in the new factory.

Non-rivalry is important because free markets are not capable of organizing the production and use of non-rival goods as efficiently as they do in the case of rival goods. The reason is that under the free market system the incentive to produce something comes from the property rights that the producer can exert over the output, rights that can be sold on the open market. This generally works well for society in the case when the output is a rival good, and it is appropriate for each user to pay for the right to use the good.[11] But in the case of a non-rival good, once the good has been produced it costs society nothing to allow the good to be used over and over by any number of people, so efficient resource allocation requires unlimited free use of the good. This will not happen if each user has to pay the producer a fee for each use. The kind of inefficiency that can be created by privatization of a non-rival good is the same as if mathematicians had to pay the heirs of Leibnitz, the inventor of calculus, every time they used they took derivative. Rather than put up with the nuisance most of them would find some second best workaround, and the result would be a decrease in the quality and quantity of mathematical analysis.

[10] Romer (1990).

[11] Of course the good must be “excludable” as well as rival; that is, it must not be possible for people easily to use the good without the owner’s permission. The key issue for the present discussion is however rivalry, not excludability. Private enterprise will not produce a non-excludable good under any conditions. An excludable nonrival good will be produced but the problem is that allowing the owner to exclude users of a non-rival good, through fees or other means, is socially inefficient.

On the other hand, if an innovator who has created a non-rival IP good is not allowed to charge for its use, this will reduce or even eliminate the reward to innovation. And of course if the rewards to innovation are reduced then we will see less innovation, and hence less technological process and less economic growth.

Resolving the Non-Rival Problem: Patents

The patent system provides one way of resolving, at least to some extent, the tension between rewarding the production of non-rival IP, which requires the inventor to be paid, and allowing free use of the IP, which requires that users not pay for it. The patent system does this by making a distinction between the object or activity that an innovation makes possible, such as a new process or a new machine, on the one hand, and the abstract knowledge that constitutes the non-rival aspect of the idea. So, a patent rewards the inventor of the better machine with an exclusive production right, for a limited period of time, which enables the inventor to become a temporary monopolist or to sell or license the right to someone else. In return, the patent also requires the inventor to disclose the knowledge of how to build and use the machine, so that it is freely available to others who wish to use it in R&D.

Resolving the Non-Rival Problem: Open Science

Open science provides an alternative system for resolving the tension between rewarding production and allowing free use. As described by sociologists of science such as Merton (1973) and Ziman (1994), scientists are rewarded not just by pecuniary gain but also by the acknowledgement and respect of their peers. The currency of science is citation. The person credited with discovery of an idea is explicitly cited when others use the idea in their own published research. The more often a scientist is cited, generally speaking, the greater his or her prestige in the scientific community. In addition to the personal satisfaction that such prestige brings, a high rate of citation frequently brings increased job opportunities, promotions, salary increases, outside offers, and consulting opportunities. In addition, prestige can be self-reinforcing, because it attracts invitations to give prestigious lectures and more generally creates a more receptive audience. Of course many of these benefits are pecuniary in nature, but they all flow through the channel of citations from one's peers, without which the scientist is likely to remain unrewarded, psychologically and sociologically as well as financially.

The same reward system that encourages the production of ideas in open science also gives maximal incentive to the dissemination of ideas. In science, as in other areas of academia, the rule is publish or perish. No credit goes to the scientist who discovers something without publishing the results and thereby putting the ideas into the public domain where they can be discussed, verified, debated, used, improved, and possibly refuted, by others.

Neither the patent system nor open science provides a perfect resolution of the tension between rewarding production and facilitating dissemination. Patents arguably provide a stronger incentive to produce new technologies, and a stronger incentive to produce technologies of immediate commercial relevance. But the disclosure requirement is often inadequate to allow the free use of patented ideas, especially when the potential user faces the threat of litigation by the original patent holder in the event that follow-on research leads to an idea that competes with the original idea. Such litigation has become quite common in high-tech industries, where companies like Google spend hundreds of millions of dollars acquiring portfolios of patents in order to reduce the danger of being sued. Innovators can be held up by someone who demands an exorbitant fee to settle a suit for violating an obscure patent that the follow-on inventor was unaware of at the time of the invention or that the inventor thought would not be regarded by any reasonable judge to be in violation of the patent. For many companies with shallower pockets than Google, the threat of litigation is powerful enough to discourage them from using patented ideas at all, despite the disclosure requirement.

4 Interactions between industry and academia

How Businesses Gain from Interactions with Universities

Many businesses have a lot to gain from engaging each other in technological endeavours. Businesses that make use of leading edge science need to keep up to date with the scientific frontier. Many have found that the best way to do this is to maintain close relations with university research, through strategic partnerships, consulting relationships with top scientists, sponsoring university research projects, undertaking joint research projects with academic scientists, and helping to commercialize technologies developed in universities. Many businesses also encourage their own scientists to participate actively in the scientific community by attending conferences and publishing in academic journals. This is not only to keep in touch with the leading edge but also so that the business can evaluate the merits of their own scientific personnel using the same sort of measures of research and publication performance as are used in university hiring, tenure and promotion decisions.[12]

Although private research labs focus mainly on applied research and development (R&D), they also carry out a significant amount of basic scientific research (although not as much as they did 20 years ago). According to the National Science Foundation (2012), over 19 percent of all the basic research conducted in the United States in 2009, measured by the dollar value of expenditures, was performed by private enterprises. Indeed, Nobel Prizes have been won by scientists in the R&D laboratories of AT&T, IBM, Smith Kline and French (now GlaxoSmithKline), Sony and General Electric.

Even those businesses that do not have their own independent research labs can benefit on occasion from access to university research, for help in solving particular technological problems that stand in the way of introducing a new product or process. Having access to lab equipment and to scientific personnel can give a company a critical competitive edge.

How Universities Gain from Interactions with Businesses

Just as industry gains from being in touch with the frontiers of academic science, so too do university scientists frequently benefit from contacts with industry. As Nathan Rosenberg (1982) has argued at length, the connection between science and technology involves important feedbacks from technology to science. Privately conducted R&D, aimed at solving mundane practical problems arising in profit-seeking business enterprises, apparently far from the realm of pure science, has often been the source of fundamental scientific breakthroughs. For example, Pasteur was searching for a remedy to problems of putrefaction in wine-making when he made the discoveries that created the science of microbiology. Torricelli was working on the practical problem of devising a more efficient pump when he demonstrated that the atmosphere has weight. Joule was searching for power sources for his father's brewery when he discovered the principle of the conservation of energy. The world of commerce and industry often poses

[12] Cockburn et al. (1999).

problems of genuine interest that require deep research in what Donald Stokes (1997) has called "Pasteur's quadrant," that is, the set of problems that are not only of immediate practical importance but also require deep and original research for their solution.

Because of these considerations, university science works best when the universities keep abreast of the problems and challenges facing private industry, and keep informed about new technologies that are continually arising and posing new scientific challenges. Academic research that maintains an ivory-tower distance from the broader community tends to become sterile. This is true especially in engineering disciplines but to some extent it holds true in almost all fields. Rosenberg and Nelson (1994) have argued, for example, that a great strength of the American university system, as compared with most European systems, is its openness to connections with industry, commerce, agriculture and government. Its willingness to let challenges and opportunities arising in these other sectors of society shape not only the research that takes place within their realm but also the programmes they offer to students.

To illustrate, American universities formed separate departments of computer science well before any European university chose to do so. Getting an early lead was no doubt critical in putting American universities on the path to becoming leaders in the field. Canada's own University of Waterloo was among those early leaders that continue to excel. As another example,[13] chemical engineering had its origin as an academic discipline at MIT in the United States when Arthur D. Little unified the study of what had been a welter of different manufacturing processes. He combined such diverse industries as petroleum-refining, rubber, leather, coal, food-processing, ceramics and glass, sugar-refining, explosives, paper and cement, by showing that all such processes could be decomposed into a small number of "unit operations," which were common across all applications. Little's creative insight undoubtedly owed much to his extensive consulting activities in a variety of different industries, the kind of activities that would have been looked upon with much less respect by academics in Europe at the time than in the United States.

5 How Canada can get the most out of university research

<u>Raising business R&D expenditures</u>

The shortfall of business R&D recorded in Figure 3 above constitutes the most obvious source of Canada's relative lack of productivity in technology transfer. Broadly speaking, technology transfer requires university expertise to provide research and business expertise to do the development. Both kinds of activity are expensive, and they are complementary. If Canadian businesses continue to rely on universities to do the kind of development activities for which universities do not have a comparative advantage, the quality of Canadian universities will be compromised and the process of technology transfer will suffer. How to encourage Canadian businesses to engage more actively with universities is a problem that should be given the highest priority by our federal government.

[13] See Rosenberg (1998) for a concise account of the emergence of chemical engineering as an academic discipline.

<u>Promoting academic excellence</u>

Economics teaches us the value of working with market forces and incentives rather than trying to fight them. Even when a case can be made for regulatory intervention in markets, the intervention is unlikely to succeed unless it ensures that people are appropriately rewarded for behaving in the way intended by the regulator. This in turn requires the regulator to understand what kinds of rewards people will respond to. In the particular case of collective intervention in university research, it is crucial to understand the nature of the rewards to which the researchers will be responding.

If Canada is going to get the most out of university research[14] then we need to give incentives to scientists to interact with private business, and to behave in ways that are likely to produce the most fruitful interactions with private business. There is considerable evidence that the most successful technology transfer comes from the scientists and engineers who are the most highly rated on general academic grounds.[15] This evidence reinforces the message derived from the statistics presented in section 2 above to the effect that the most productive universities in terms of technology transfer are also those who are most highly rated on purely academic grounds.

Understanding the Incentives for Top Scientific Researchers

So we need to make sure that the very best academic scientists are induced to interact with Canadian businesses, and to do this we need to ensure that they are rewarded in ways that will bring about desired result. This brings us to the critical point, which is that academic scientists, and especially the very best academic scientists, are driven mainly by the desire to advance research agendas that will lead to discoveries that are highly regarded by their peers, or, for those who are relatively indifferent to external rewards, discoveries that best satisfy their own curiosity. Various studies[16] have confirmed that even those scientists that contribute the most to technology transfer are motivated not so much by the prospect of patent revenues; instead what mainly interests them is the challenge of dealing with interesting problems that fit into and help to advance their research programs. Many of them are constantly seeking out applied problems that lie in Pascal's quadrant. Some of the scientist interviewed by Colyvas et al. (2002) stated that they eventually sought patents on their discoveries not because they wanted to profit but because of pressure from foreign collaborators who wanted to please their home sponsors or pressure from their own university officials. In fact for many scientists the prospect of having to spend time working on filing patent applications instead of on their own research can be quite discouraging.

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[14] These remarks do not necessarily apply to support for other post-secondary institutions such as community colleges, which are naturally more practically oriented and less in a position to be fostering fundamental advances in scientific knowledge than the universities that constitute the focus of this commentary.
[15] See, for example, Agrawal and Henderson (2002), Di Gregorio and Shane (2003) Geuna and Nesta (2006), Perkmann et al. (2011).
[16] For example, Colyvas et al. (2002), Lam (2009).

Although it is difficult to find convincing quantitative evidence about what really motivates scientists (or anyone else, for that matter), one can at least ask them. An interesting study by Alice Lam (2011) did just this, by asking a total of 771 scientists from 5 of the top UK research universities to rank the importance of various factors in motivating their research, on a scale from 1 (irrelevant) to 4 (very important). The sample was biased in favor of commercially-oriented scientists, 73 percent of whom said that they had engaged in at least some form of commercialization, including 39 percent whose commercialization went beyond just collaboration with business and involved patenting, licensing or company formation. The results are shown in Table 2 below, which indicates the percentage of respondents rating the factor as 3 or 4. The three factors scoring highest in this study all relate to the opportunities to advance the scientist's research agenda. Personal income gain, while not irrelevant, was the least important of all the factors according to this table.

Table 2

Motivating factor	Percentage 3s and 4s
To increase funding and other research resources	83%
Application and exploitation of research results	70%
To create opportunities for knowledge exchange/transfer	66%
To satisfy your intellectual curiosity	59%
To build personal and professional networks	59%
To provide work placement or job opportunities for students	41%
To increase your personal income	27%

What is going to encourage the most effective technology transfer from university research is an academic environment most attractive to those scientists who are most successful on purely academic grounds: the ones who are primarily driven by the urge to advance their scientific research agenda. The kind of environment that appeals most to such academic researchers is not one in which the primary emphasis is on application-driven research, and in which most of the money is being directed towards those projects of greatest perceived social or commercial value. Instead, such researchers are attracted to environments in which the primary emphasis is on cutting edge fundamental research, the kind of research most likely to satisfy scientists' curiosity or to enhance their prestige in the scientific community.

In contrast, the emphasis of Canada's policy with respect to university research has been shifting away from academic excellence and towards financial and commercial viability. For example, the Networks of Centres of Excellence program, which was started in 1997, was intended to ensure that academic researchers would participate in the "national system of innovation" (Networks of Centres of Excellence Program, 1997). Industrialists are appointed to the boards of the Networks in order to maximize the likelihood of commercialization. The OECD (2012) describes how Canada's granting agencies have been shifting funds away from curiosity-driven research and towards commercialization. The vision statement of NSERC on its website puts as much emphasis on fostering collaboration between industry and science as it does on fostering basic science.[17]

One lesson to be drawn from this analysis is that Canadian granting agencies should increase the emphasis on academic excellence, over perceived practical utility, when allocating university research grants. Although it may seem paradoxical, the evidence supports the view that the greatest benefit to society will come from scientists for whom practical utility and financial reward is a minor consideration. The best way to attract such scientists to Canada is to redirect our research support towards the problems that are most challenging from a scientific point of view, not towards those that bureaucrats view as most likely to lead to commercial success.

As Agrawal (2008) rightly points out, raising the academic prestige of Canadian universities is likely also to make them more attractive to businesses that are seeking to strengthen their academic ties. If we could get just one Canadian university into the top 10 of the World University Rankings this could do more to encourage successful business/university interaction and technology transfer than any of the targeted application-based project support that is currently being offered by Canadian granting agencies.

Technology transfer offices

When commercialization does take place, university researchers need all the help they can get. The typical scientist is not experienced in commercial or legal affairs, and the best ones are not interested in spending their time gaining such experience. They need the help and support of experts. That is one of the primary roles of technology transfer offices, which are often critical in managing the interface between the frequently conflicting worlds of business and academia.

An example of the sort of potential conflict that TTOs can help to manage or even avert is provided by the famous case of Dr. Nancy Olivieri,[18] a University of Toronto faculty member who was conducting clinical drug trials at the Toronto Hospital for Sick Children, sponsored by a Toronto pharmaceutical company. In 1996, concerned that the trial results were revealing potentially dangerous side effects, she warned her patients and published her results in the New England Journal of Medicine, both of which

[17] It states that NSERC's mission is to foster"basic research, projects involving partnerships between postsecondary institutions and industry, and the training of Canada's next generation of scientists and engineers."

[18] The facts of this case are detailed on a webpage of the Canadian Association of University Teachers: http://www.caut.ca/pages.asp?page=199

actions put her in conflict with a nondisclosure agreement that she had signed on her own, without the aid of any TTO. The case generated a great deal of unwanted conflict and adverse publicity for all involved, most of which could have been avoided if the researcher had sought the advice of a technology transfer officer before signing her nondisclosure agreement. She would almost certainly have been warned in advance that although this might be a routine sort of agreement from the point of view of her business partner, it was not the sort of agreement that any academic researcher should enter into. Standard practice among TTOs is to permit a business partner or sponsor to delay publication of research results, but for no more than 60 days. Nondisclosure is limited strictly to those aspects of the business that the investigator learned during the course of the research that are unrelated to the research findings themselves; and all contracts must allow for unrestricted use of the research findings in teaching and non-commercial research.

Technology transfer offices today not only provide university researchers with business and contracting expertise; they also help industry to deal with university partners, many of whose attitudes they might find puzzling and frustratingly un-businesslike. On the face of it these offices seem to be doing a good job on both fronts. But the fact that research inputs in Canadian universities have gone up drastically over the last two decades without a correspondingly drastic improvement in the universities' commercialization outcomes suggests that there is room for improvement.

One way that TTO support could be strengthened is by having them focus more on facilitating faculty interactions with business and less on generating licence revenue from IP, as recommended by the above-mentioned OECD report. There is growing evidence from US studies to the effect that most of the technology spillover from university research comes through channels other than patents and licenses. For example, Cohen et al. (2002) report evidence from the 1994 Carnegie-Mellon Survey on Industrial R&D, in which businesses were asked to name the most effective channel through which they benefitted from academic research. In most industries the leading answers were publications, informal exchanges and communications with scientists, and consulting. Patents and licenses were hardly mentioned at all. Likewise, Colyvas et al (2002) examined in detail 11 cases of important technology transfer emanating from Stanford and Columbia, and found that in several cases patents played no role in the commercialization process. Agrawal and Henderson (2002) interviewed 236 professors of Mechanical Engineering and of Electrical Engineering and Computer Science (the two highest patenting departments) at MIT, who reported that on average only 6.6 percent of their influence on industry came through patents and licenses, while 18 percent came through publications, 27 percent through consulting and 17 percent through training students.

My conversations with officials in several Canadian TTOs revealed that many of them already are downplaying the generation of IP revenues and are trying hard to foster industry/university interactions along a multitude of different dimensions. But the Canada-US productivity gap in technology transfer suggests that there may be room for further improvement along this important dimension.

Another way that TTOs could be made more effective is through increased competition. Right now the faculty in many universities are dependent on the particular TTO in their own university for support in commercialization. In effect, each TTO has a local monopoly in providing such services. It might be worthwhile for universities to consider following the lead of the University of Waterloo, where faculty members are, to use the expression of Litan, Mitchell and Reedy (2007), "free agents," and can make use of the TTOs services but are also free to pursue commercialization through on their own or through other agencies.

Moreover, the federal government, and to a lesser extent provincial governments, have already started to create supra-university institutions that offer such expert assistance in commercialization and in fostering interactions with the business community.

A model for such interactions would be MaRS Innovation, a CECR created in 2008 with assistance from the Ontario government. MaRS Innovation acts as the official agent for commercializing the intellectual property of 16 different academic research institutions (universities and teaching hospitals) in the Toronto metropolitan area. Its mission is to identify research with commercial potential and to build businesses on the basis of that research, through partnerships, licensing agreements and spinoffs. It operates on a large enough scale to provide expert services to a diverse collection of inventors and investors both, and has spun off over a dozen different companies and helped to bring over 500 different technologies to the stage of ready to be licensed. Although it might not be possible for other provinces that do not enjoy the concentration of high-level research that exists in the Toronto metropolitan area, to duplicate the success of MaRS, it is worth considering pursuing ways of exploiting economies of scale that might exist by having supra-university TTOs that can serve more than a single university. Indeed, this is already happening with Springboard Atlantic, which helps to commercialize the research of 18 colleges and universities in Atlantic Canada.

Other CECRs have also been providing alternative solutions to the commercialization process, such as the Centre for Drug Research and Development (CDRD) which is also supported by the government of British Columbia, also TECTRA which works in geomatics, GreenCentre in green chemistry, and the Canadian Digital Media Network. My main point here is that finding a workable pattern of such agencies would probably be helped by having more provincial governments getting involved and by the extra dose of competition that free agency of university researchers would provide. Different universities have different research specialties and there are different regional and provincial specialties, each with its own special needs for commercialization. So there is certainly no one-size fits all solution to providing faculty members with assistance in commercializing their research. But, as Litan, Mitchell and Reedy have argued, competition is a powerful force for providing tailor made market solutions to complex problems in many areas, solutions that often cannot be predicted in advance.

There are potential drawbacks of the free agent system, but they should not be decisive in all cases. Of course some provision ought to be made to compensate the university for its role in supporting its faculty members' research, in the form of a minimal share of royalties and profits. Also, there is a danger that that inexperienced faculty members can make mistakes if not forced to obey the advice of their more commercially knowledgeable TTOs. But, as the example of the University of Waterloo shows, the system can work in many cases where faculty members are keenly aware of commercialization potential and are already involved in commercially oriented research networks. Litan, Mitchell and Reedy also point out the experience of the Wisconsin Alumni Research Foundation (WARF), a nonprofit organization that functions as TTO for the University of Wisconsin at Madison. Even though no faculty member is required to use WARF to commercialize their research, the vast majority choose to do so because of WARF's reputation for excellence. This is just an example of the kind of outcome that a more competitive environment might produce under the free agency system.

National Research Council Institutes

Another simple way to provide more competition for university TTOs would be to carry out the recommendation made in the Jenkins report[19] to reorient the NRC Institutes with a view to transforming them from independent research agencies into agencies for fostering collaboration between universities and business. The most recent federal budget has allocated 67 million dollars to reorient the NRC institutes towards more business-relevant research. I believe this money could be better spent by sticking closer to the original Jenkins report recommendation, which emphasized collaborative industry/university research. This could be done by changing the Institutes missions to include offering “concierge” and other services that would in effect compete with those offered by university TTOs.

The NRC is to some extent a relic of the era before the federal government adopted a comprehensive policy with respect to science and technology. It was created in 1916 to carry out research when needed by the government, especially military research. Its operations are spread over 20 different institutes, and it has undertaken valuable research. Perhaps the two most widely known successes of the NRC are the coordination of the joint research project with Spar Aerospace in Toronto in the 1980s to develop the Canadarm used in the US space program, and the research that led to the development of Canola in the 1970s. But on the whole, these institutes are not as well placed as are universities to undertake the kind of scientific research that a country needs to remain on the frontiers of science and technology in the modern world. As Rosenberg and Nelson (1994) have pointed out, one of the features that has helped to give US universities their preeminent role in higher education in the world is the fact that they integrate teaching and research into the same institution. In contrast, in many European countries, research is largely undertaken through national research labs and teaching is done in universities and academic institutions. There are key synergies between teaching and research that are lost when the two activities are divided between separate institutions.

Nothing is more effective for the training of graduate students than to have them involved as soon as possible in research activities. This happens routinely in first-class North American universities, where the graduate students are typically a vital part of the intellectual life of the department. At these universities, direct research collaboration between the graduate students and their teachers is something that happens routinely as a result of the fact that the teaching takes place in an atmosphere permeated by the values of research.

The same can be said, although to a lesser extent, about undergraduate teaching, which universities are increasingly trying to integrate with research. Getting undergraduates involved in their professors’ research activities helps them to acquire the spirit of intellectual curiosity and excitement that exists on the frontiers of research, a spirit that is especially valuable in our era of global competition and rapid technological change. Teaching divorced from research can easily slip into rote learning of established

[19] Industry Canada (2011).

facts, whereas teaching integrated with research builds our collective capacity to cope creatively with change and uncertainty.

The integration of teaching with research also enhances the research process. Few activities are more fruitful in advancing one's research agenda than teaching a course focused on that agenda to bright graduate students. These students bring a fresh viewpoint to the subject, and their intelligent questions and even criticisms can be invaluable. Moreover, if they can be motivated to write dissertations in the teacher's own area the teacher will learn a lot from mentoring, and even collaborating with, the dissertation research. Quite often the graduate student and teacher enter into collaborative research that extends well beyond the PhD thesis. And the best graduate students, who are destined to become leaders in the teacher's discipline, are now at a formative age when the teacher is in a position to shape their thinking and hence to advance his or her own research agenda.

All in all, it makes good sense to redirect the focus of federal research support away from the NRC institutes and towards universities that can benefit from and contribute to these synergies with teaching. Meanwhile the question remains of what to do with the institutions left behind when this reallocation takes place. Since there is a case that can be made anyway for engaging some new institutions, outside the confines of any particular university, in the facilitation of industry-university collaboration, why not use the institutions we already have, institutions which the government is in any event already committed to supporting?

Open access publication

As I have argued above, publication in academic journals is one of the most effective channels of technology transfer. The more open the publication, the more benefit society will get from it. Discoveries published in journals that are hard to locate and costly to access are less likely to have an impact on industry than discoveries that are easily and freely accessible. Many journals have become very expensive. One survey[20] conducted in 2011 found that the average annual subscription fee paid by libraries for journals of chemistry was more than US$4,000. A few journals charge libraries more than US$40,000 a year for a subscription.

Most journals post their contents online, but behind a pay wall, so there is a charge per article read or downloaded. Even if the fee per article is only a few dollars that is enough to make it prohibitively expensive for the curious layperson, or even an expert that is not connected to a university or other institution with a well-funded library, to get ideas from browsing through the relevant literature.

The problem of inaccessible journals runs counter to the spirit of open science, and there has been a strong reaction against it in academia, not just in the sciences but in all disciplines. This reaction has spawned a new kind of academic journal, called open access journals, whose articles can be accessed and

[20] "Periodicals Price Survey 2011: Under Pressure, Times are Changing," http://www.libraryjournal.com

read at no cost by anyone with an internet connection. This movement is spreading fairly quickly, to the point where Richard Poynder, one of the prime movers of open access, has estimated that about 30 percent of the world's academic journal articles are now available on open access sites.[21] But that leaves a full 70 percent still unavailable to all but a few privileged insiders.

In the United States, the National Institutes of Health (NIH), the main US agency responsible for allocating federal funds for research in the life sciences, places all publications resulting from their funded research in an open access archive called PubMed Central. In effect, this makes the journals in which such articles are published open access journals, at least with respect to the NIH-sponsored articles. It is likely that within the next year the National Science Foundation (NSF), the second largest US federal granting agency, and the Departments of Energy and Agriculture will do the same with all the papers resulting from their research grants.[22] In the United Kingdom, the government recently announced a policy that will require the results of all publicly funded research to be published in open access journals.

Canada has now joined this movement in the area of life-science research. Since April 2010, a freely accessible online repository called PubMed Central Canada (PMCC) has been accepting submissions from researchers sponsored by the CIHR. Since January 2013, the CIHR has required that all journal articles resulting from research they sponsor be made freely accessible, either in the journal's website or in an online repository like PMCC within one year of publication. Meanwhile, PMCC has been encouraging all other Canadian granting agencies to partner with them.

One of the simplest and least cost ways that other Canadian granting agencies, especially NSERC and SSHRC, could raise the benefits that Canadians derive from university research would be to follow the lead of the CIHR by providing an archive like PMCC and insisting that any research they fund be published with open access.

Anyone who has studied economics will realize of course that open access does not mean free. Operating an academic journal entails a significant cost, for editorial work, for the refereeing process that screens out low quality articles, for printing and distributing hard copies, for maintaining a web site and many other activities necessary to the functioning of a good journal. If publishers cannot charge people for reading their journals online, then the demand for hard-copy subscriptions will fall, and the journals will need to find some other means to cover their costs if they are to remain in operation.

The way publishers of open access journals make up for this shortfall of subscription revenue is through article processing charges (APCs) that are billed to the authors of articles accepted for publication. The APC is typically in the range of one to three thousand US dollars per accepted article. The CIHR allows researchers to use their grant to cover APCs, as do the NIH and NSF in the United States. The current

[21] "Open and Shut by Numbers," http://www.poynder.blogspot.com

[22] "US Moves to Provide Quicker Access to Publicly Funded Scientific Research," New York Times, February 23, 2013.

proposal in the United Kingdom is to make block grants to universities to cover APCs, but this may be changed to the US system before the policy is fully implemented in 2014 because it has come under a great deal of criticism. Among other things, the peer-review process that granting agencies use to select the best research proposals would probably do a better job of allocating the available APC funds to their best uses than would the politico-bureaucratic process that allocates block grants to universities.

So if NSERC and SSHRC were to follow the lead of the CIHR they would have to allocate more money to each successful research grant, to cover the APCs. But this additional cost could be offset to a large extent by making less money available to universities to cover the costs of hard-copy subscriptions. Indeed even if some libraries continued to demand the same quantity of journals the price per journal would likely come down as publishers shifted their fees away from subscriptions and towards APCs.

One potential downside to such a policy is the possible deterioration of quality control that might result if journals started relaxing their refereeing standards in order to compete for APCs. But as far as I am aware there is no evidence that this has compromised the integrity of U.S. research in the life sciences, most of which is funded by the NIH, which has been enforcing its open access policy since the year 2000. Nor does there need to be any serious loss of copyright protection, since journals (and authors, if applicable) can still retain copyright over their articles to prevent bulk downloading for commercial purposes.

Bayh Dole

IP rights have been much talked about in connection with university research, especially in the United States with regard to the Bayh-Dole Act of 1980 that enabled universities to claim ownership to IP generated by their publicly funded research. Indeed, in 1999, the Expert Panel on the Commercialization of University Research[23] set up by the federal government recommended that Canadian universities all adopt a uniform system of IP rights based on the model of Bayh-Dole, a recommendation that was recently reinforced by the OECD (2012).

There is some evidence that Bayh-Dole had a positive effect on technology transfer in the United States. In the 20 years following its passage, for example, the number of universities engaged in technology licensing increased eightfold and the volume of university patents increased fourfold.[24] However, it is not clear that Bayh-Dole was the direct cause of these increases in technology transfer activity. For one thing, as we saw in section 2 above, roughly the same kind of increases also took place in Canada over the same period even though there was no comparable change in legislation in Canada. Moreover, as Colyvas et al (2002) point out, the post Bayh-Dole surge in university patenting reflected a trend in microbiology and software that had already started in the 1970s.

[23] Advisory Council on Science and Technology (1999).

[24] Mowery and Shane (2002)

Also, as Colyvas et al (2002) also found in their case studies, licensing and patenting are often not important considerations in major instances of technology transfer. As already mentioned above, it is doubtful that the best scientists and engineers were much influenced by the financial rewards created by Bayh-Dole. In any event the situation in Canada now in terms of ownership of IP by universities is quite different from what it was in the United States prior to Bayh-Dole. None of the federal granting agencies in Canada claims any ownership rights to IP generated from the research they fund. Canadian universities already have as much financial incentive to engage in technology transfer, and as much ability to grant exclusive licences to business partners, as was granted to US universities by Bayh-Dole.

Nevertheless it might be worthwhile for Canada to consider copying one aspect of Bayh-Dole. Specifically, Bayh-Dole provided a standard template for sharing the rewards from commercialization of university research, a standard that made the process of technology transfer more predictable and hassle-free for all parties. This helped to simplify the process for faculty members who are averse to becoming entangled in transactions that take time and effort away from their research agendas. Moreover, it encouraged business partners to engage in the process because they could count on a simplified transactions process that was relatively predictable and did not vary much from one university to another.

At present there is a large variety of different IP ownership policies in place across Canadian universities. In some, the university claims sole ownership rights. In others, the rights reside in the individual researcher, and in others the researcher has the option of keeping the rights or ceding them to the university and letting its TTO undertake the work and expenses of patenting, licensing and other aspects of commercialization in exchange for a share of royalties and other revenues. Moreover, each university seems to have its own set of protocols for sharing IP rights with business partners.

Thus it would make sense for federal granting agencies to help standardize IP ownership rights and the way they are shared with researchers and business partners. The importance of this standardization would not be so much to create the right incentives for research but to simplify and regularize the process of technology transfer. As Colyvas et al (2002) argue, one of the main roles of universities in the technology process is to monitor, facilitate and regulate the transactions between researchers, who normally do not want to be bothered with the business end of things, and their business partners, who normally would rather be dealing with more business-like counterparties. The more we can do to help standardize those transactions the better off we will be.

This is not to argue that there is a single template that would fit all cases, or even that there is any authority who could effectively force all universities (and their faculty associations) to adopt that template. But it would be worthwhile for the federal government to consider following the lead of the UK government, which has produced the “Lambert toolkit;” a set of 4 alternative template agreements to be signed by universities and business partners engaged in collaborative research, and another 5 templates for the case of consortiums involving more than 2 institutions, each of them designed to cover a class of situations that are considered to be fairly common, and a step-by-step guide to help parties work out agreement. Each of these templates suggests revenue sharing arrangements and other details that could act at least as a starting point for negotiations and as a focal point to help facilitate agreement. Although the jury is still out on the success of the Lambert toolkit, there would be relatively little cost to seeing whether these template agreements, and the associated users' guide, could be modified to fit the Canadian context. At best this would help speed up the process of technology transfer and encourage more businesses to get involved in collaborative research with universities; at worst it would produce yet another set of government documents that no one reads, but at least its cost could be contained.

6 Summary

University research in Canada has made a significant contribution to technological progress, and therefore to growth in our productivity and in our living standards. But there are several ways that contribution could be made even more significant. This investigation has led me to the following six recommendations:

1. Canadian businesses need to spend more on development expenditures, in order to play their role in the technology transfer process as effectively as do their counterparts in the United States. Encouraging more Canadian business R&D will enhance the transfer of knowledge from universities to society as a whole, not just directly but also indirectly, because university researchers that are free to specialize in what they do best, which is research, rather than having also to undertake the kind of development activities that are best conducted in the business sector, will generate a higher level and quality of knowledge to be transferred.

2. Federal granting agencies should reorient their system of allocating public funding of academic research to give more weight to overall academic excellence rather than immediate practical payoff. The universities and researchers that generate the greatest benefit to industry are those that are rated most highly on general academic grounds, and the best way the agencies can help attract top university scientists and engineers is to fashion a research environment that is focused on supporting the kind of research these academics like to engage in.

3. University Technology Transfer Offices play an important part in facilitating industry/academy interactions, bridging the gap between the cultures of commerce and open science. They could do a better job if they would focus more on fostering general interactions between business and faculty, and less on generating licensing revenue. As in many other industries, they would probably also do a better job if there were more of them offering competing services. The federal government has taken the lead in creating supra-university organizations that are empowered to offer their services to university researchers. Provincial governments should consider taking more efforts to create such institutions, and universities could do a lot to make sure that the most efficient institutions end up doing the bulk of commercialization in each specialty and each region by allowing their faculty members to be free agents when looking to commercialize their research findings or to find business partners or sponsors, rather than forcing them to go through a TTO with monopoly rights.

4. The Recommendations of the Jenkins report to the effect that National Research Council Institutes should be converted from research organizations into agencies devoted to fostering university/industry interactions should be carried out, because the locus of scientific research in Canada should be in universities where the synergies between research and teaching can be most effectively exploited. An effort should be made to convert at least some of these institutes into the kind of supra-university technology transfer office envisioned in the previous recommendation.

5. The NSERC and SSHRC should follow the lead of the CIHR by insisting that all journal articles resulting from research that they fund be made freely accessible to the public, and creating an internet repository for all papers resulting from such research. This is one of the least cost, simplest, and most effective ways in which Canada could start to get more social benefit from university research, by making research findings available at very low cost to anyone, not just to those at universities and other institutions able to access the high cost journals in which most scientific findings are now published.

6. The federal government should develop a set of standard protocols, based on the example of the "Lambert toolkit"[25] in the UK, that universities could adopt to regularize the sharing of IP ownership and licensing revenue between university, researchers and business partners. This would help to make universities become more accessible and predictable resources for businesses that wish to partner with them and for those that seek their help in solving technological problems.

[25] Intellectual Property Office (2011)

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