optimum online
THE JOURNAL OF PUBLIC SECTOR MANAGEMENT

INNOVATION = INVENTION + COMMERCIALIZATION: A SYSTEMS PERSPECTIVE

T. A. Brzustowski
Vol. 36, Issue 3, Sep 2006

Introduction

This paper describes the process by which inventions derived from basic university research in science and engineering are commercialized. The process is described in terms of two systems: an invention system and a commercialization system. This is not a theoretical model, nor an idealistic goal. It is an empirical depiction of what actually happens in Canada, a picture of the innovation process learned over the years from the experience of those who have actually been involved in it. It is not a static picture; it changes as new local approaches prove successful and the process is eventually improved across the country.

For present purposes, we define innovation[1] as

innovation = invention + commercialization

This definition suggests a framework for what follows, an examination of the two systems that correspond to its two aspects.[2]

But before we go there, we must first consider a third system, the basic research system, shown in figure 1.

There are five inputs to the basic research system:

1. the intellectual contribution of the professors and students doing the research;
2. the input of world research results and expertise both into the preparation of the research proposal and into the peer-reviewed funding competition that provides quality control;
3. the infrastructure of facilities and services provided by the universities: the so-called indirect costs of research;
4. the university salaries of most of the professors leading the research;[3]
5. the discovery grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) to cover the direct costs of the research that include the support of the students involved.

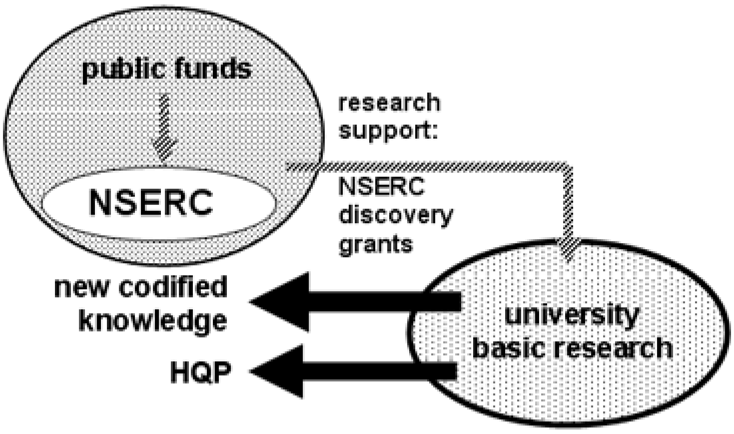

Figure 1. The basic research system in science and engineering

The main criterion for the discovery grant is excellence, both of the proposed research and of the applicant's demonstrated record. With that criterion, the funding process achieves a reasonable probability that the funded research might produce world-class scientific discovery.

To keep the graphics simple, we show only the last input explicitly. The other four can be treated as implicit in the NSERC process for funding basic research in the universities.

The time scale of the basic research system can be taken as the five years that is the normal duration of discovery grants. It is also characteristic of the time taken by Ph.D. students in science and engineering to complete their degrees.

There are two outputs of the research system, and both are shown in figure1:

1. new codified knowledge, communicated to the world through peer-reviewed scientific publications in scholarly journals;[4]

2. highly qualified people with advanced degrees.

The first output defines the main thrust of the research system from the perspective of researchers, but the second one is often considered equally or even more important, particularly by many industrial leaders. Inventions are not an output of the basic research system; it was set up for discovery, not invention.

The invention system

The invention system related to basic research is shown in figure 2. Its output is an invention, the culmination of three steps: i) formulating an idea for an invention based on the research and usually done by researchers themselves, ii) recognizing that it might indeed have the potential to become a new product in the market, and iii) demonstrating that potential to those who will pay for defining the invention, improving it, patenting it, etc. Figure 2 also shows that the market is part of the invention system since it is the locus of any commercial opportunities that the invention might present. Steps ii) and iii) usually require expert help from people who specialize in recognizing inventions. Generally, that work is done within the university. Some universities have the funds to pay for it themselves; others rely on external funding.

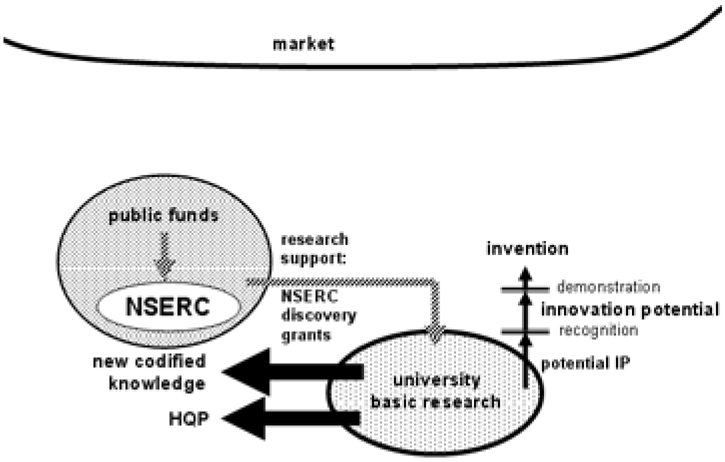

Figure 2. The invention system associated with basic research in science and engineering

Inventions arising out of the results of basic research are considered potential intellectual property (IP). They are communicated by disclosure to the institution.[5] Publication of the underlying research results is generally delayed until the necessary first steps of patent protection have been taken. Such inventions are outputs of the research and contributions to knowledge that could prove very important, but in the Canadian university culture, they are generally considered less valuable for the careers of professors than discoveries published in the peer-reviewed scientific literature or graduate students successfully supervised.

The commercialization system

The commercialization system is coupled to the invention system, and operates downstream of it. The connection between the two is made only when an invention has been recognized and demonstrated within the invention system. The next step is to demonstrate that potential to those who would pay for proving the concept of the invention, defining and improving the IP, and protecting it.

Not a linear process

This sequence of systems should not be interpreted as the "linear model" of innovation, according to which an innovation emerging out of basic research proceeds in linear fashion through a sequence of steps from discovery to product. On the contrary, each of our three systems is fraught with false starts, dead ends, changes in direction, and feedback loops, but in broad terms, invention follows research and commercialization follows invention.[6]

The people who make the connections

The early steps of recognizing and demonstrating the invention are crucial, and their success depends on the ready availability of some very highly qualified people. Not all researchers can realistically assess whether their own inventions have innovation potential. It may be easier in "Pasteur's Quadrant", i.e. when the goals of the research are both a new understanding and a new use, as is often the case in biomedical and engineering basic research. But it is likely to be difficult when the research lies in "Bohr's Quadrant", i.e. its goal is only to produce a new understanding, as is much more the case in the natural sciences.[7] As a result, it is very important for universities to have people available who understand the science and know the related markets well enough that they can provide advice that might be credible to both the inventor and the institution. They should also be familiar with the sources of funding for the early stages of the commercialization process, whether from the university itself, government programs[8] or private investors. The same people should then be able to turn around and look outward from the laboratory and the university to launch the full commercialization process.

Needless to say, such people are rare. Most are trained on the job, and there is something of a "brain drain" from the universities, both to financial institutions and to start-up companies seeking management expertise to take them forward. However, specialized training for these people is now being offered outside the university system.[9]

The commercialization system associated with basic research is shown in figure 3. The circle represents the process of proving the concept, and defining, improving and protecting the IP which has to be done whether the IP is to be licensed to an established enterprise or be the basis of start-up company. This stage of the process is strongly affected by the university's policies and practices which, in turn, reflect the institution's goals and capabilities for undertaking such work.

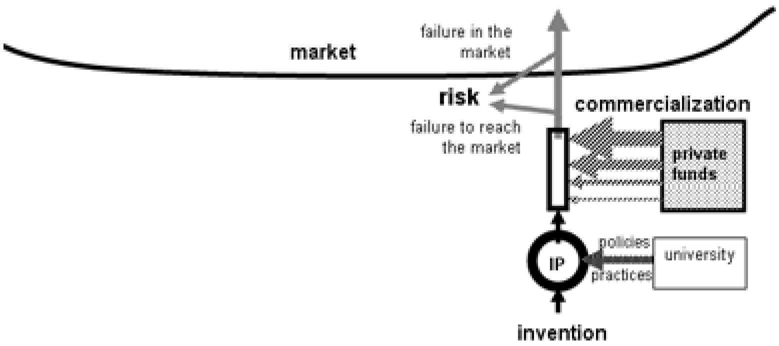

Figure 3. The commercialization system associated with basic research in the case when a new company is started up to exploit the IP

University IP policies

In some Canadian universities, the IP belongs to the institution. In others, it belongs to the inventors. In others still, the ownership is shared according to some prescribed formula. In some universities, IP ownership is established within the collective agreement with faculty. This variety of approaches has been controversial. Advocates of the "university owns" policy promote it as neat and predictable, the one approach that gives potential licensees only one owner to deal with and avoids any downstream uncertainty about ownership when the IP is exploited. Advocates of the "inventor owns" policy insist that it promotes faculty entrepreneurship and ensures that the delicate early steps of commercialization receive the time and attention that only an entrepreneurial inventor can offer. Success stories do not settle the issue; there are plenty of successes under both policies.

University practices

The success of the commercialization system obviously depends on the skills and experience of the people involved in the universities' so-called "tech transfer offices".[10] However, the culture of these organizations depends also on the universities' goals for their activity. If the overriding goal is to ensure that the tech transfer office is not a cost centre to the university, quick deals that provide early cash flow might be emphasized, and bigger long-term propositions might not be given prompt attention. If, on the other hand, the university's goal is to achieve much bigger amounts of IP income to reduce the shortfall in the operating budget, then small deals might be given scant attention, potential big deals would become a priority, licensing agreements for promising IP would be negotiated at length with detailed provisions for downstream benefits, and IP might become overpriced. But if the university's goal were to be getting its most promising IP as quickly as possible into the hands of those who might use it for new wealth creation in the Canadian economy, then the emphasis might be on providing quick user-friendly service to industry.

The box above the circle in figure 3 represents the start-up case. The inputs of the inventor's technical expertise to provide "commercial improvement" of the IP and of management to move the process along are treated as implicit and not shown in the diagram. The focus is on the input of investment in the traditional four stages from start-up to third-stage (or mezzanine). The output is a product to be offered in the market.

Cost and risk

At this point, it is useful to emphasize two essential differences between the invention system and the commercialization system. The first is cost. The investment in the research that leads to the invention is far less than the cost of commercializing it. The author has seen no firm numbers on this, but conventional wisdom has it that commercialization is orders of magnitude more expensive than invention. Apparently the ratio is between 10 and 100 times at the low end (e.g.: some software) and 1,000 to 10,000 times at the high end (e.g.: pharmaceuticals). The research investment is largely public; the much larger investment in commercialization is largely private.

It might be useful to have research done to produce more precise numbers, but two fundamental obstacles stand in the way. First, the basic research leading to the discovery that suggests any invention is done by many people in many places over many years. As a result, perhaps the best one can do is to add up the traceable costs only in the laboratory from which the invention ultimately emerged. Secondly, the cost of taking a particular invention to market is not straightforward to arrive at, given that the process is non-linear with false starts, feedback loops, opportunity costs and other complications. Moreover, if it were known accurately, it would be a very important piece of competitive intelligence for the company involved, not likely to be made public until long after the fact, if at all. It may, therefore, be the case that our understanding of this aspect of commercialization will have to continue to rely on anecdotal information and conventional wisdom.

The second big difference is the nature of the risk encountered. In the basic research system, the risk is scientific, and it is kept to a minimum by peer-reviewed competitions for research support. A failed research program will hurt the reputation of the scientists involved and will represent a loss of the public funds spent on it. But that loss may not be total. Dead ends identified in one scientist's research may save time and money in the work of other scientists in related areas. By contrast, the risk in commercialization is financial, and involves much larger sums. A promising product may fail to make it to market for a variety of reasons, some of which may be unrelated to the product itself. Or it may be introduced in the market and fail there because of lack of customer acceptance, bad timing, ineffective marketing, unexpected competition, changing market conditions, or any other reason. There is no peer review to protect the commercialization investment, only due diligence by the investors and the commitment, business skills, energy and experience of the entrepreneurs.

The successful innovation

When commercialization succeeds and the resulting innovation succeeds in the market, the loop closes. There are benefits to society in the form of a new product that is meeting a need that hadn't been met before. There is new value-added activity and wealth generation in industry, with the obvious economic benefits in terms of earnings and employment that flow from that. The investors receive a return on their investment in commercialization, the university receives royalties or an equity position as the source of the IP, and the tax system provides a return to government on the research funds expended. The benefits to the inventor are not shown explicitly, since they may come through the return on investment or through the university's share.

The successful case is illustrated in figure 4.

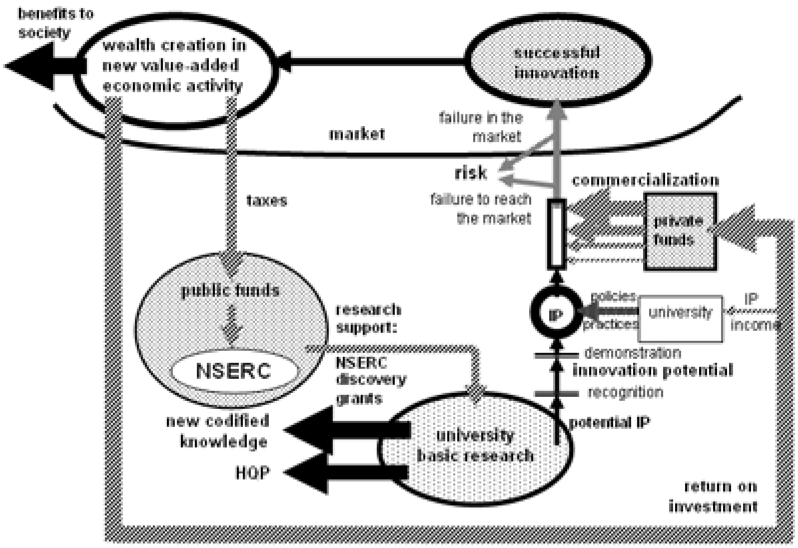

Figure 4. A successful innovation arising out of basic research in science and engineering

Perhaps the most important observation to make is that a relatively small amount of public research support given to the right researchers in the basic research system may ultimately catalyze a much larger flow of private investment in the commercialization system, and a flow of benefits through the economy.

Observations

The model of the invention system and the downstream commercialization system make it possible to provide some clear answers to important questions.

Three connections between research and wealth creation

If Canada's goal is to obtain a significant economic impact from the investments in university research in science and engineering, then we must have the capacity to link industry and university research effectively by:

- industry hiring university graduates who are up to date in modern technologies because they were taught by professors who do research, and are therefore capable of contributing to industrial R&D;
- bringing industrial problems whose solutions require new knowledge directly to the universities, and either entering into university-industry research partnerships, or having the necessary research done under contract; the commercialization of any innovations arising from the research is in the hands of the companies involved.
- commercializing the inventions that occasionally emerge from the results of basic research in the universities.

The first connection is well established in Canada, and works effectively on a significant scale, with particular advantages offered by cooperative education. The university-industry research partnerships in the second connection are also well established and involve hundreds of companies in projects of high quality. The third link is a much more difficult and less well understood process, but one that seems very attractive to the public and to governments. The purpose of this paper has been to help make it better understood, and to point the way to improvement.

Improving the commercialization of inventions out of basic research

- The first and most obvious conclusion is that to commercialize inventions emerging out of basic research one needs excellent basic research to produce important results that may suggest valuable inventions, a good invention system to identify possible inventions, and an effective commercialization system to take such inventions to market, with good linkages among the systems.
- A good commercialization system must have enough good people with the right skills, working effectively within appropriate policies driven by the right goals, and enough investment capital available in the right amount at the right time and on the right

terms.

- The early-stage activities of recognizing and demonstrating the innovation potential of inventions, and then defining, improving and protecting the intellectual property are probably best done within the university, close to the research, and they must be carried out promptly. The people required to do that need to be very skilled. They are scarce in Canada.

- The commercialization of an invention is much more expensive than the research that led to it. Moreover, the private investment in commercialization is exposed to commercial risk, in contrast with the public investment in the research that was exposed to scientific risk. The skills required for commercialization are specialized and very different from those for research, and researchers should generally not be expected to have them. In fact, managers experienced in bringing innovations to market are essential in both existing companies that license new IP and start-up companies that are created to commercialize particular inventions.

The return on public investment in research

- The return on the public investment in basic research can be inferred from figure 1. Both outputs of basic research have value, but the highly qualified people (HQP) produced in the process may have a more immediate local economic impact than the new codified knowledge. The value of these HQP depends on what they produce in the economy, and that cannot be evaluated without reference to the economy's receptor capacity for their knowledge and skills.

- Nevertheless, if we take one's lifetime salary as a measure of contribution to the economy, an estimate of the order of magnitude of this return on investment can be produced as follows: about 50 percent of all research grant funding is spent on graduate students; when they graduate these students typically attract starting salaries roughly 4 times higher than what they are paid from research grants; if we assume their working lives on average will last 6 times longer than their graduate studies, and that their average salary will be double their starting salary, then their contribution to the economy as measured by their salaries during their working life will be 48 times what was invested in them as graduate students, or 24 times what was invested in the research grants that supported their studies – all of that assuming, of course, that they continue to function in the Canadian economy. If that return occurs over 30 years, the annual compounded ROI implied is 11 percent per year. And we must remember that this number ignores the value of the research results produced by these people during their education, as well as the substantial economic multiplier for the jobs these HQP perform in the economy.

- In defining the return on investment in research, one must be clear about whose return is to be considered and on what investment. It seems that the "big picture" ROI should be the value of the benefits to society shown at the upper left of figure 4 (jobs, investments, taxes paid, availability of new goods and services, improved health and safety, etc.) divided by the public investment in the research. However, this obvious measure is not practical. The total benefits attributable to the successful innovation and the total cost of the research that produced the underlying invention (as distinct from the value of the last research grant to the lab from which the invention emerged) pose an enormous accounting challenge. In addition, this indicator could not be used for policy purposes without data on the fraction of all research grants that lead to successful innovations.

- A different approach has been taken by the Association of Universities and Community Colleges (AUCC).[11] It focuses on the IP income to the universities. This is shown in figure 4 by the thin dashed arrow emerging out of the return on investment halfway up the right edge of the diagram. The AUCC indicates that Canadian universities collectively earned $51.0 million in IP income in 2003. However, they spent $36.4 million to manage their IP, for a net income of $14.6 million. The same report acknowledges a public investment of $1.6 billion in university research in 2002-03. On the face of it, therefore, the financial impact on the universities is negligible. The net IP income is about 0.1 percent of total university costs, and it represents only 0.9 percent of the public investment in research and infrastructure that year, and little more than 0.1 percent of the investment since 1997-8.

- However, these numbers also suggest a more important conclusion. An educated guess at the impact of university research on the whole economy can be made based on the gross IP income of the universities. The $51.0 million represents only a fraction of the new economic activity associated with the licensed IP, but how big a fraction? The author is not aware of any research on this, but the behaviour of Canada's Top 100 R&D spenders[12] is suggestive. On the average, these companies spend about 4 percent of sales revenue on research and development (R&D). For want of data, we shall assume that this percentage applies also to those companies that have actually licensed university IP. If their licence payments are in the same proportion, then the

2003 revenues associated with university inventions would have been about $1.27 billion.[13] That would represent an 80 percent return on the $1.6 billion public investment in 2002-03.

But since the economic impact always lags the research, a more realistic ROI might be the new revenue in one year relative to the accumulated investment in earlier years. According to AUCC, the total public investment in university research from 1997-98 to 2002-03, a period of significant change in Canadian funding of university research, is $6.78 billion. On that basis, the 2003 revenues estimated above suggest that the ROI is a respectable 18.8 percent. The numbers in this paragraph and the preceding one may be rough, but the difference in their orders of magnitude suggests strongly that university research is important for the economy, even if it doesn't create much new income for the universities.

Conclusion

The commercialization of inventions arising out of basic research is a difficult and complicated process, but it works well in Canada. Looking at it in a systems perspective helps to identify areas where improvements can be made. The economic impact of university inventions on the economy is already large, even if its impact on university funding is small. Both can probably be increased significantly by improving the invention system and the commercialization system, but the impact on wealth creation in the economy should take priority in driving those improvements.

Tom Brzustowski is RBC Professor for the Commercialization of Innovations in the School of Management of the University of Ottawa and Chairman of the Board of the Institute for Quantum Computing at the University of Waterloo. He was Vice-President of the University of Waterloo and Deputy Minister in the Ministry of Colleges and Universities of Ontario. Between 1995 and 2005, he was President of the Natural Sciences and Engineering Research Council of Canada

---

1 *Innovation is a generic term, whose meaning includes both having a new idea and putting it into action. The definition of innovation used here is appropriate when discussing research in science and engineering. It includes both process and product innovations, in both the goods and services sectors. Finer shadings of these innovations into incremental vs. revolutionary, disruptive vs. sustaining is not pursued in the present discussion. (In fact, innovations emerging from basic research are often disruptive of existing practices, and some are even revolutionary.) Discussion of social innovations, organizational innovations, marketing innovations and institutional innovations is also beyond the scope of this paper.*

2 *In spite of this definition of innovation, we will resist the temptation to call the combination of the invention system and the commercialization system the innovation system, since that term is already widely used for a broader concept that includes these two systems and much more.*

3 *Strictly speaking, only a portion – typically 1/3 – of the salary of a professor doing research should be considered as an input to the basic research system. The exceptions are professors who hold Canada Research Chairs, NSERC Industrial Research Chairs, and other endowed Chairs or Professorships whose salaries come from the research sponsors.*

4 *According to King (David A. King, "The scientific impact of nations", Nature, 430, 15 July 2004, pp 311-316), Canadian researchers contributed 4.58 percent of the world's scientific publications in 1997-2001, and 5.81 percent of the 1 percent most-cited papers in that period, ranking sixth behind the US, UK, Germany, Japan and France on both counts. To put these numbers in a larger perspective, Canada has about ½ percent of the world's population and 2 percent of the world's economy.*

5 *Disclosure is required by NSERC and independently by some universities.*

6 *This sequence would not hold in the case of innovation triggered by feedback from the customers of an established company, a mechanism that is widely believed to be the dominant driver of innovation in industry.*

7 *For example, experimental physicists are famous for being ingenious in devising solutions to their experimental problems. But once the experiment works, many would prefer to get on with exploring the questions they set out to study, having to solve new experimental problems along the way, rather than looking to see if the solution to their*

last experimental problem might be the basis of an invention that could meet a need in some market.

[8] *Some universities have created small funds for just this purpose. NSERC's I2I program is a small and very competitive program also designed to meet these needs.*

[9] *Among recent initiatives to increase the numbers of such people, a successful one is the program of Westlink Inc. that takes candidates from science and from finance, and trains them through internships "on the other side of the table".*

[10] *Technology transfer office is the generic name for these organizations. Individual institutions use a variety of names, such as "industrial liaison offices", "innovation foundation", etc. which can reflect a variety of structural arrangements within the university.*

[11] *Momentum – the 2005 report on university research and knowledge transfer", AUCC 2005, ISBN 0-88876-231-3, pp 22, 30, and 31.*

[12] *"Canada's Top 100 corporate R&D Spenders", RE$EARCH Infosource Inc., November 12, 2004*

[13] *While the accuracy of this number cannot be established, it is possible to comment on its plausibility. A useful publication (NSERC, "Research Means Business - A directory of 141 companies built on NSERC-supported university research", 2005, ISBN 0-662-41209-5), lists the revenues of the 47 companies that chose to report their revenues, out of its total list of 141. That revenue total is just above $3 billion. The list of 47 includes most of the big revenue generators in the list of 141(mostly 2005 data and some for 2004). At first glance, the $1.27 billion of revenue imputed to university IP might seem like a very large fraction of that total, given that the largest of these companies undoubtedly generate revenues from many products. However, it must be remembered that these 47 companies constitute only a tiny fraction of all companies engaged in R&D in Canada, and they include only a handful of the top 100 R&D spenders, and are thus unlikely to be the only ones using university-generated IP. Therefore, all things considered, the $1.27 billion seems a plausible number for Canadian industrial revenues associated with university IP.*