ICI Canada

A PERSPECTIVE TO SUPPORT SCIENCE INVESTMENT FOR INNOVATION

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Overview

R&D funders, especially in the public sector, struggle to understand the chain of activities, divergence and convergence of scientific research to create knowledge and technologies leading to innovation. A simplified perspective that demystifies the technical details and provides a basis for understanding the risks, returns and performance of R&D investments at various points in the chain would support a more strategic approach.

Definitions

It is important to start with clear definitions for science versus technology and for invention versus innovation. Science is the pursuit or creation of knowledge while technology is the practical application of knowledge. Neither knowledge nor technology are necessarily useful in their own right at the time they are created. It sometimes takes decades to recognize their true value. For example, today we consider the discovery of the DNA double helix in 1953 as a transformational moment in the history of science. However, at the time of the discovery the question of which molecules carry heredity information was still an open question. Now, some seventy years later we are on the verge of the era of personalized medicine.

Invention is the conceptualization, demonstration or creation of a product or process for the first time. Innovation, on the other hand, is the process of translating an idea or invention into a good or service that creates value and/or for which customers are willing to pay. These two terms are often wrongly interchanged. Edison was an innovator - he monetized his inventions. However, many inventions can lag the innovation by decades. For example, the transistor was invented in 1947. However, the first widespread practical use of the transistor was delayed by 15-20 years, not because the applications were not envisioned but because the process for the reliable, cost-effective manufacture of transistors was not available. It is also important to remember that the invention of the transistor was preceded by 30-40 years of semiconductor materials chemistry and physics.

Finally, it is helpful to distinguish between incremental innovation and disruptive innovation. Incremental innovation is the continuous (or incremental) improvement is an existing product or service to maintain competitiveness. It is normal business for most companies. On the other hand, disruptive innovation is new product or service that provides a discontinuous change in cost-performance or provides an entirely new offering that displaces existing ones. Generally, there are broad socio-economic impacts associated with the disruptions, e.g., e-retail which is enabled by the convergence of several technologies.

The Innovation Chain

Innovation is often viewed through the lens of R&D activities, starting with scientific research through to technology development and deployment. This science/technology push perspective (top of Figure 1), while pervasive, is not an accurate description of how innovation actually takes place. The "counter-current" from an unmet market need in the market towards fundamental research is equally important and sets up a number of feedback loops that drive the innovation system.

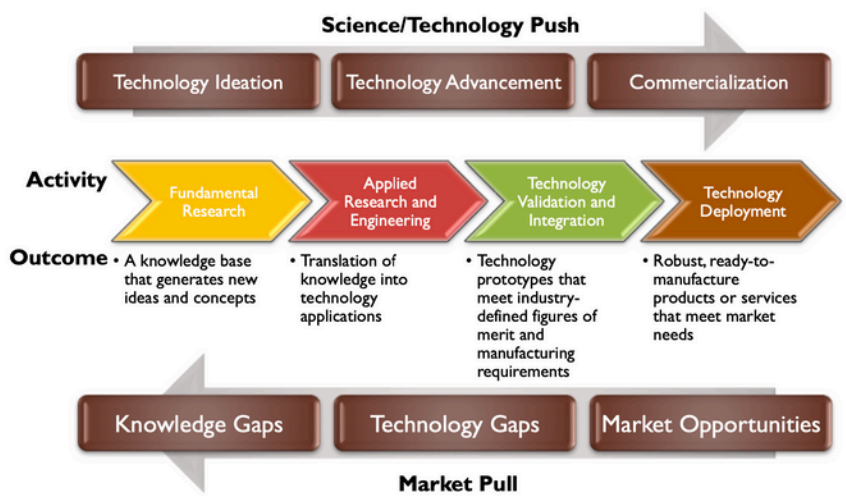


Figure 1. The innovation chain as a virtuous cycle of push and pull.

To be clear, scientific research is not necessarily a requirement for technology innovation - innovation investments do not have to feed the beginning of the chain. This can be seen from the pull perspective (bottom of Figure 1). If technologies are available to solve a problem then there is no need to invest in the invention of new technologies. Similarly, if there is sufficient knowledge to invent a new technology, there is no need to invest in fundamental science.

Figure 1 presupposes that there exists an underlying vision and strategy that is driving the innovation priorities. Who determines what the market opportunity actually is? For a company this is normally set by senior executives and tends to be narrowly focused on a specific market or market segment. At the level of a provincial or federal government, the vision and strategy could be more aspirational, focusing on solutions to emerging socio-economic challenges with solutions that require a decade or even a generation to develop.

Science/Technology Push versus Market/Customer Pull

Let's look at two extremes in order to get a better understanding of the need for a balance between push and pull. In the absence of "pull", the focus is on creating new technologies without a clear understanding of how they will be used - a "solution in search of a problem".The left side of Figure 2 shows the sequence of outcomes from discovery through to deployment. The right side of the figure shows the various activities and outputs as well as some of the questions that drive the R&D decisions. It is the typical researcher perspective that feeds a knowledge base and invention portfolio. It is important to recognize that most disruptive innovations emerge from science/technology push (see below).

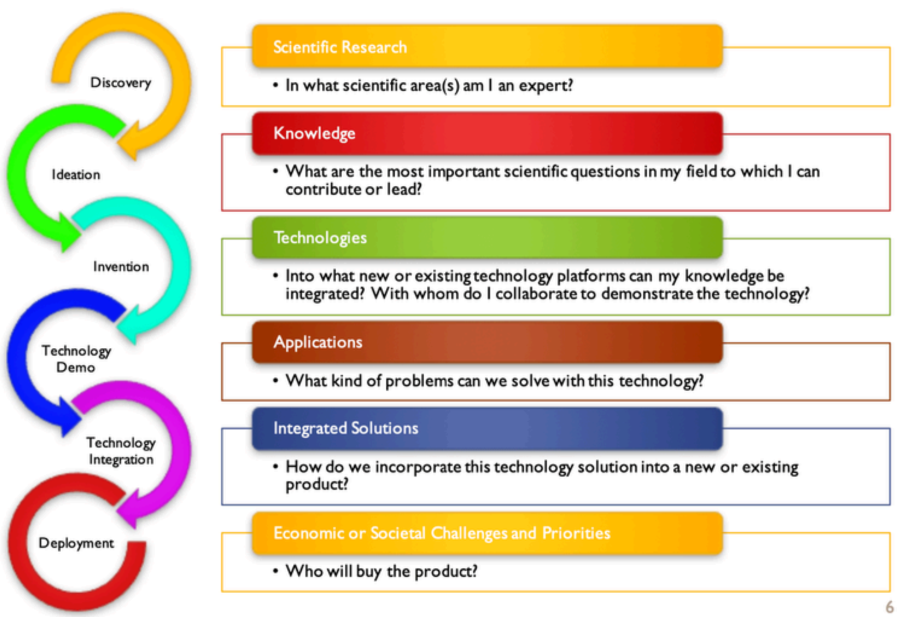


Figure 2. Innovation from a science/technology push perspective.

On the other hand, pure market/customer pull focuses on creating technologies to solve specific problems. It is technology agnostic - "a problem in search of a solution". The owner of the problem provides figures of merit that define the ideal solution but is open-minded about how the problem can be solved. For example, managing the rise in hospital acquired infections could be solved by prevention (improved hygiene), rapid diagnostics and patient isolation, improved remediation (i.e., drugs) or some combination of the three. The problem owner (provincial governments) may define a solution as: (1) reduce the rate of infection from 1.6 per thousand to 0.4 per thousand and (2) reduce the management cost from $5B to $1B annually. Figure 3 shows some of the questions that drive decision-making at various stages.

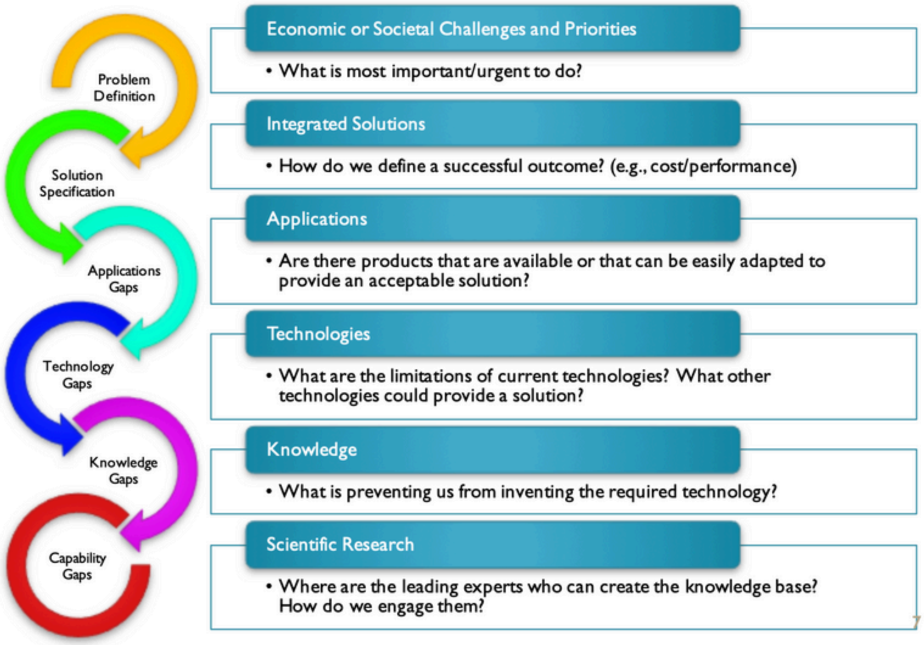


Figure 3. Innovation from a market/customer pull perspective

A vibrant innovation ecosystem sustains a healthy balance between the push and pull perspectives. The confluence of push and pull is the foundation of open innovation. Funders in open innovation forums and other similar top-down approaches rely on the researcher driven "push" approach to generate proposals the cover a wide range of technologies as possible solutions. Conversely, top down aspirational challenges motivate the community to think in certain directions and can help to shape the knowledge base of an organization or even a country. Ultimately, this optimizes the opportunity for unanticipated applications of technology (disruptive innovation). A vibrant innovation ecosystem maintains a balance between the two.

The Gap Analysis - Getting the Best Return on R&D Investments

The gap analysis in Figure 1 is helpful for deciding where R&D investments will have the greatest impact.

Applications Gaps: If technologies are available to provide a solution, there is no need to invest in R&D. There are a number of organizations that excel in integrating off the shelf technologies into new tools and applications. For example, the INO in Quebec is particularly good at assembling commercially available optical and electronic components into new, innovative instruments to meet their customers' needs.

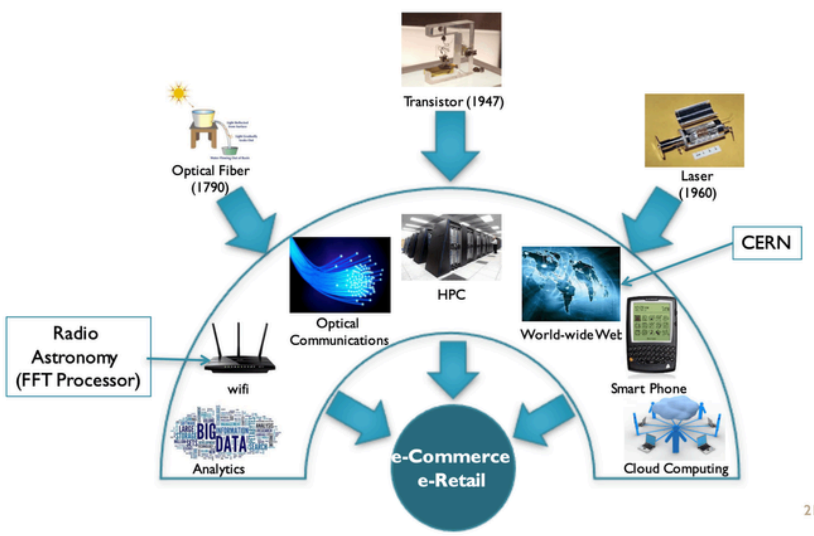
Technology Gaps: In the absence of available technologies that can be adapted to provide a solution it is necessary to invest in the development of customized technologies that meet the figures of merit of an acceptable solution.

Open innovation is increasingly the preferred approach. Few organizations (if any) have the breadth and depth of R&D capabilities to develop ideal solutions to complex problems. Open innovation models provide an opportunity to explore and evaluate a wide range of possible technology solutions.

Knowledge Gaps: While it is true that in many cases new technologies are created from existing knowledge, it is inevitable that barriers to the invention of new technologies will require new knowledge. It is important to understand that problem-driven fundamental science to support the development or evolution of technology is different from curiosity driven research (which is equally important).

Capability Gaps: Because this top-down approach illuminates areas in which knowledge is lacking, it is natural to evaluate where the necessary expertise and facilities can be found. This becomes an important build or buy issue in cases where the areas of expertise are core to a business or in the national interest. An example could be cybersecurity expertise. Most countries recognize that it is in their national interest to build and advance that capability internally.

Example: e-Commerce/Retail from a Technology Push Perspective



Firstly, the base technologies (first layer) were first demonstrated decades (and in one case a couple of centuries) earlier. The concept of an optical fibre was demonstrated over 200 years ago. The first attempted use of a "light pipe" using glass rods was about 90 years later. While the physics was not understood before the early 20th century, it is now the conceptual underpinning of optical telecom. The transistor was first demonstrated in 1947. This was preceded by decades of fundamental science in the physics and chemistry of semiconductors.

The so-called “solid state revolution” of the 1960s initially replaced vacuum tubes with transistors. However, it was really the advent of the transistor radio that started the path towards miniaturization and the creation of new manufacturing technologies for silicon. The continuous halving of the cost per device (Moore’s Law) also drove increased performance and reliability, ultimately leading to desktop and high-performance computers. The laser was first demonstrated in 1960. It took 10-15 years before practical applications (e.g. CD players) began to emerge. Lasers now underpin optical telecom and are likely the basis for future quantum information technologies and advanced manufacturing.

Secondly, the enabling technology platforms (second layer) used combinations of the base technologies. It is important to note that the enabling technologies (with perhaps the exception of the smart phone) were not stand-alone integrated solutions. They clearly have accelerated our ability to solve problems but were not customized to address a specific socio-economic challenge. Some of these enabling platforms were developed to solve particular local problems in “big science” facilities. For example, the key component of wifi routers was actually developed by radio astronomers. ARSTechnica.com has an interesting analysis in which they point out: “Its path to becoming the "WiFi inventor" started when a CSIRO astrophysicist, John O’Sullivan, was tasked with building a high-speed wireless network. He didn't begin building a team for the project until the early 1990s—well after many of the key technologies already existed, and the ultimate relevance and success of O’Sullivan’s project is now one of the most heavily litigated issues in the history of technology. CSIRO's $229 million payday is just the latest example.” Similarly, it is well known that the progenitor of the internet was developed by CERN to manage communication and information exchange amongst the hundreds of teams working on particle physics problems.

Thirdly, while none of the enabling technology platforms were disruptive in their own right, the combination of these platforms led to an innovation that has far reaching social and economic consequences. In this example, the emergence of e-retail and e-commerce have had profound societal and economic impacts. None of these were planned and only a handful of insightful futurists may have foretold their coming.

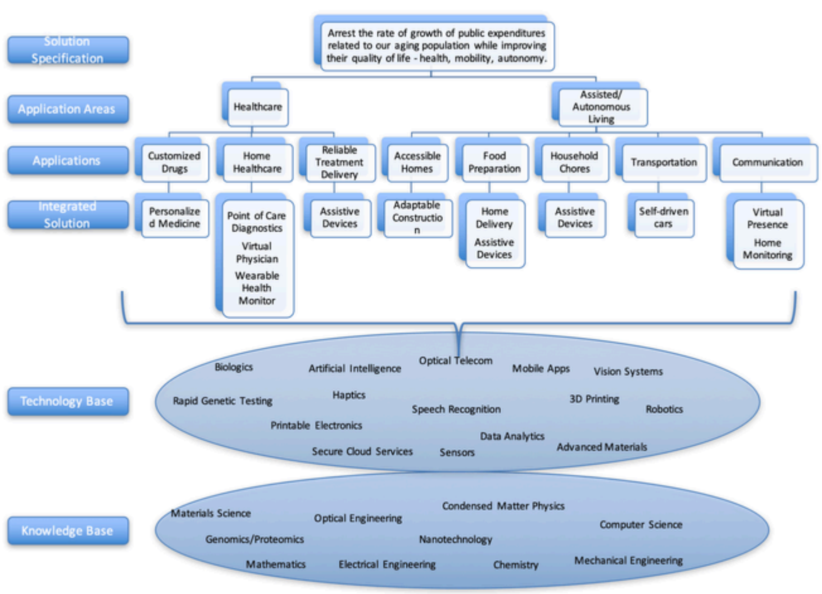
There are other examples of disruptive innovations that emerge primarily from a technology push. The key take-home message is that driving innovation exclusively from the top-down (i.e., only by problems or opportunities with a line of sight from today) inevitably misses the small fraction of truly disruptive ideas.

Example: An Aging Population from a Market Pull Perspective

Recently, the NRC published a summary of a Game Changing Technologies crowd-sourcing discussion that took place in the winter of 2015. The intent was to engage a broad group of Canadians in a discussion of a number of Canadian and global challenges that we will have to address over the next few decades if Canada is to maintain a high standard of living and its place in the world. The dialogue addressed seven challenges: Cities of the Future, Rural and Remote Communities, Aging Population, Security and Privacy, Classroom of the Future, Next Generation Healthcare and Sustainable Food Industries. These are aspirational challenges that can only be solved on a generational time scale - ones that can inspire our most creative researchers and can only really be driven by our federal and provincial governments. The role of the government is not to champion a solution but to clearly define the problem and the figures of merit that define and acceptable solution. The example below is simply to illustrate how a well- articulated, technology agnostic problem can lead to a wide range of potential solutions.

Problem definition:

Like all first world nations, Canada faces an aging population with about one quarter of Canadians expected to be over 65 by 2035. Our aging population will face an eroding quality of life with challenges that include the management of chronic diseases (e.g., arthritis, diabetes), limited mobility and isolation from family and friends. The rising public cost of healthcare and social programs is not sustainable.



The diagram above shows the “top-down” perspective. In this simplified example, the solution specification, while succinct, provides the elements of an acceptable solution - functional outcome and cost. In reality, the solution specification would have to be further subdivided but for the purposes of this illustration this will suffice. For simplicity in this example, I have limited the “Integrated Solution” level to have the same number of elements as “Applications”. The point is really that at the level of an aspirational socio-economic challenge, there are several technological (and non-technological) threads that ultimately have a significant degree of overlap and interdependence.

The problem definition allows the areas of application to be split into health and non-health applications, which are further subdivided into specific areas of application. Note that the applications are not technology specific and can be further defined in terms of desired outcome. It also is clear that this approach has a “fractal” nature, meaning that the level of complexity increases from one layer to the next below.

The level of integrated solutions, while not prescriptive in terms of technologies, forecast the types of products that are likely to meet the solution requirements. Each of these “products” require the integration of more than one technology. Thus, at the level of technology base the direct line to an application is lost. For example, the Virtual Physician may require the integration of vision systems, speech recognition, haptics, artificial intelligence, cloud services, data analytics and mobile apps. Assistive devices for household chores may require the integration of robotics, vision systems, sensors and speech recognition.
The technology base is supported by a knowledge base that is founded (primarily) in science and engineering research (but social science issues are clearly emerging as critical success factors). The 2012 Council of Canadian Academies publication “The State of Science and Technology in Canada” provides a detailed taxonomy of science and engineering disciplines. The report also provides an assessment of Canada’s strengths and weaknesses in these areas - important insights when assessing capability gaps.

This illustration does not attempt to provide an analysis of the technology and knowledge gaps that impede our ability to deliver an acceptable solution to the problem. The combinations and interdependencies of technology platforms is far too complex for the purposes of this report. The onus is on the research community (through whatever mechanism is used to engage them) to demonstrate how a particular technology or combination will provide an acceptable solution, the extent to which existing technologies can be adapted and the focus of applied or fundamental R&D needed to develop and deliver the solution. Typically, this requires a vetting process for proposals and well-defined project and performance management.

Having a clear idea of success and an open mind regarding the nature of a solution is important. This approach is the foundation of DARPA - perhaps the most successful directed innovation program in the last 50-60 years.

The extreme performance oversight and financial controls by DARPA and the DOE ARPA-e program is not for all academics. A number of universities in the USA have chosen not to participate citing a conflict with their values around academic freedom and the right to publish. The DARPA model essentially provides milestone payments and is well known for terminating programs that miss their self-imposed milestones and deadlines. Interestingly, discussions with DARPA and ARPA-e point to two other success factors. The first is to provide a high level of autonomy to their Program Managers (each is entrusted with about $50M USD for a 5-year program). The second is the ability to take significant risks and not to be bound by the limitations of peer review. Their experience is that peer review tends to lead to a high degree of risk aversion which is counterintuitive for a program focused on potentially disruptive solutions.

There are a number of other open innovation forums that have emerged over the last decade or so. Nano-Quebec created such a forum to connect industry to potential solution providers (initially focused on Quebec universities but now expanding to be more national in scope). Syngenta and Bayer launched an open innovation site (Xeconomy) to search for the next big AgTech idea. Nine Sigma was spun out of Proctor and Gamble and has been operating an open innovation forum for some time that brings together solution seekers and solution providers. Other programs such as the X-Prize and the Gates Foundation competitions use a similar approach but are more focused on global social challenges.

Summary

It is helpful to look at the innovation ecosystem from the perspective of a balance between science/technology push and market pull. I have tried to make the point that technology disruptions that lead to disruptive innovations are opportunity driven and almost always come from the push side. The nature of these disruptions is that they are hard to predict and usually result from the integration of more than one technology platform. Countries that don't engage in exploratory, fundamental science not only limit their chances to develop these disruptions but also limit their capacity to understand and exploit new ideas and technologies once they are discovered or developed. For example, there is little doubt that a quantum information industry will emerge. Those countries which have not invested in the science will not have the opportunity to develop the technologies and establish industry leadership. The challenge with science/technology push and disruptive advances is that it is not clear where the disruptions will be or when, hence the investment decisions feel very high risk to funders. It is not practical or advisable to evaluate these risks using discounted cash-flow/ROI, as is common for investments yielding shorter term returns (it's actually more like investing in real options).

On the other hand, there are clear short and long-term challenges for which technologies will be at least part of the solution. The market/customer pull approach can create an innovation environment that optimizes our ability to develop solutions. A solutions approach to R&D has the advantage of opening the door to new collaboration opportunities that can bring together players from industry, academics and federal/provincial laboratories.

The downside of too much focus on a narrow set of problems is that adjacent opportunities can be missed.

The balance between these two approaches is essential for a thriving innovation system. How to establish an appropriate balance is an important public policy question. While this report has focused on the challenges related to innovation, science investments also support other issues in the public interest such as evidence-based public policy and global science initiatives. This adds to complexity of investment decisions by all levels of government.

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