Canadian university research in science and engineering

- the next twenty-five years

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at York University
March 10, 2004

NSERC
CRSNG

Canada

NSERC CRSNG

vision and mission

Prosperity and high quality of life for Canadians

Science and Engineering Research Canada

We invest in:

discovery

Competitive research in science and engineering, providing access to new knowledge from around the world

EXCELLENCE

innovation

Productive use of new knowledge in all sectors of the economy and society

people

Highly skilled, well educated and capable of lifelong learning

Our goal is Canadian excellence in:

CREATING KNOWLEDGE

WORKING IN ALL AREAS OF SCIENCE AND TECHNOLOGY

USING NEW KNOWLEDGE

We do this through peer-reviewed competitions in three programs

Research Grants for **basic research** in the universities

Scholarships and fellowships for undergraduate students, postgraduate students, postdoctoral fellows and some university faculty

Partnerships of universities with industry and other sectors for **project research**

NSERC also works towards its goals by exerting INFLUENCE beyond our program reach

The Vision

NSERC invests in people, discovery and innovation through programs that support university research in the natural sciences and engineering on the basis of national competitions, and ***that will continue to be our major activity.***

But in addition, NSERC will reach out across the country to meet important needs in the education of HQP, in research, and in innovation. These needs are different in different parts of Canada. To do a good job in meeting them, we will develop a local presence in the regions of Canada.

“NSERC is a federal agency that will start acting as a national agency.”

NSERC today


NSERC
CANADA
© 2001. Her Majesty the Queen in Right of Canada, Natural Resources Canada.
Sa Majesté la Reine du chef du Canada, Ressources naturelles Canada.

The new actions

People

- help to improve science and math education

Discovery

- develop and validate a national framework for “Big Science”
- support regional capacity building in research

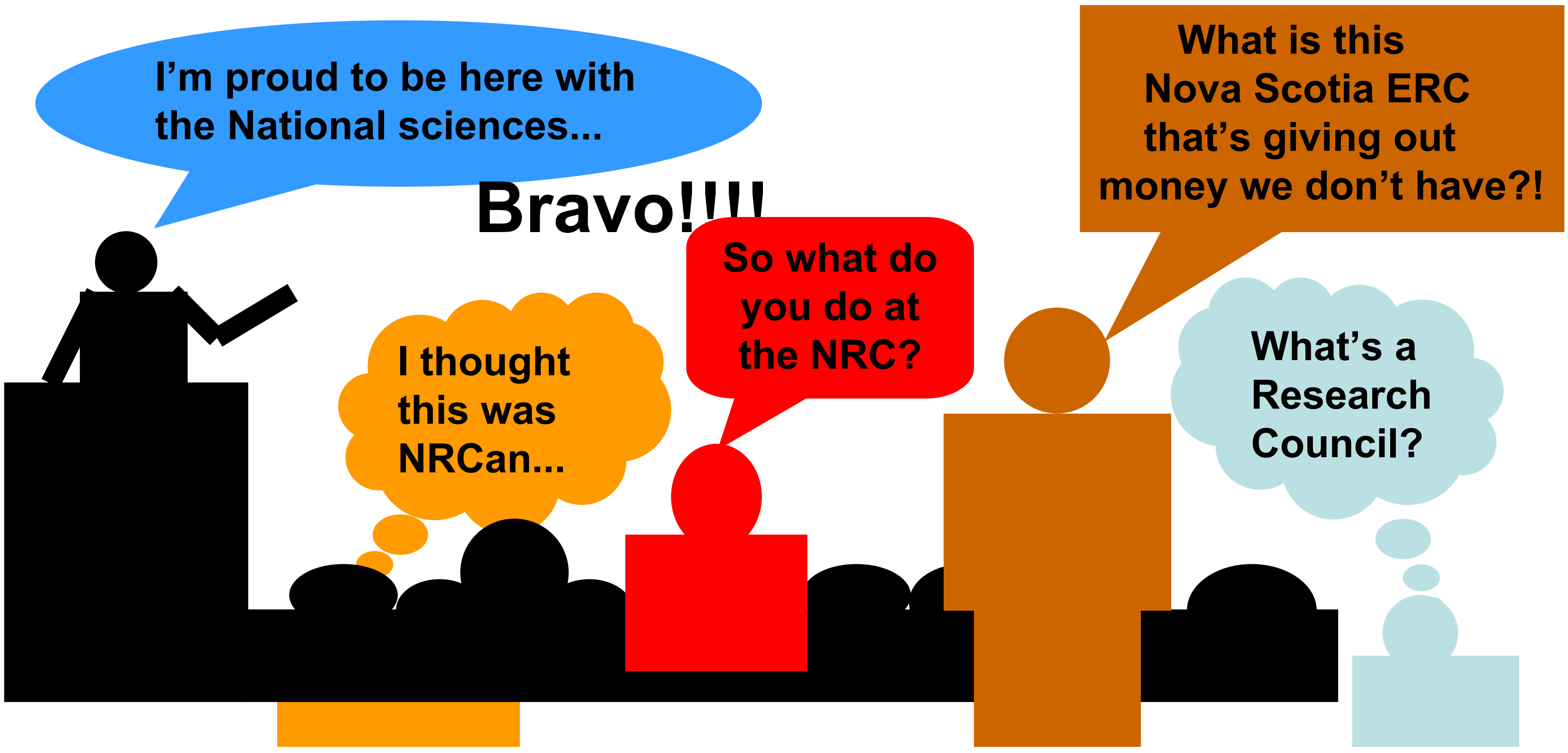
Innovation

- support community colleges helping in innovation at the community level

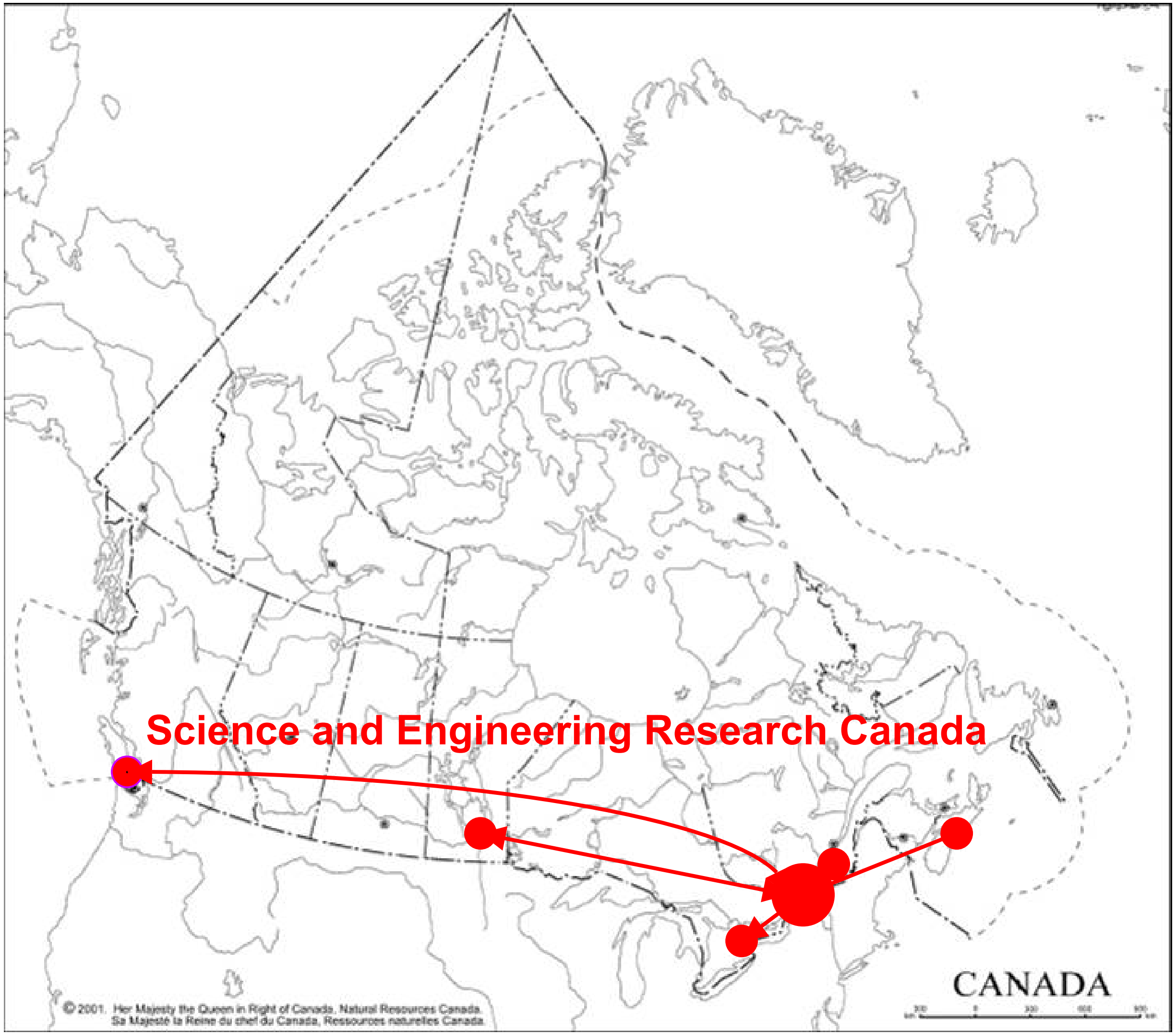
..... and to be effective in doing these new things

- develop a regional presence across Canada
- strive for public recognition by doing business under a new label

Natural Sciences and Engineering Research Council Canada



NSERC in the new vision



Initial conditions – the good news

- Emphasis on excellence
- Canadians have access to the other 96%.
- Massive faculty renewal is bringing good researchers
- Government of Canada initiatives are working
- Complementary provincial programs of research support
- Research leaders have first-rate research infrastructure

Initial conditions – the good news ..... (cont'd)

- Basic research is valued, e.g.: Perimeter Institute
- Potential economic value of university research in science and engineering recognized, and increasingly realized
- Project research in partnership with industry, government and NGO's: long-term relationships and scientific excellence
- Students educated within such partnerships becoming important in Canada's capacity for innovation.
- Good multidisciplinary national research networks

..... and the not-so-good

- Support for research rising; support for the core functions of the universities not keeping up
- Federal-provincial problem overshadowed by health care
- Canadian university researchers have less time for research
- Installation of new research infrastructure is outstripping the availability of operating funds
- Shortage of skilled people to commercialize the results of university research and create wealth in Canada

..... and the not-so-good ..... (cont'd)

- With some outstanding exceptions, Canadian industry spends relatively little on R&D, and lags international competitors in innovation performance.
- Many still believe that R&D belongs only in "high-tech" or "new economy" industries
- Most of Canada's exports are raw materials based on natural resources, with little value added in Canada
- Innovations are a small part of our exports

The approach in this presentation

The big picture -- stressing five unifying themes, rather than the details of any possible breakthroughs and discoveries:

1. **Integration**
2. **“Drinking from a fire hose”**
3. **Modelling**
4. **Institutional innovation**
5. **Commercialization and wealth creation**

These five themes do not tell the whole story, nor are they mutually exclusive, but this list provides a useful way to introduce some important ideas from the point of view of an agency that supports research in a great many fields.

But why not the details of expected breakthroughs?

- **Discoveries and breakthroughs are best summarized in hindsight, e.g.: in year-end reviews in "Science" and "Nature", in Nobel Prize citations, etc.**

- **Predictions of breakthroughs should be left to specialists**

- **Most "Foresight" exercises come up with essentially the same results**

- **But it is possible to describe some themes that are likely to shape the Canadian research to come**

Theme 1. Integration

Integration involves the exchange or diffusion of perspectives, concepts, and methods among established disciplines

Here are four areas of research, likely to become increasingly important in the next 25 years, that will involve integration both within the natural sciences and engineering and with disciplines outside the NSE.

The human being

- **integration of scientific, engineering, social and medical research in many areas of health research, including genomics, tissue engineering, imaging, bioinformatics, etc., etc.**
- **integration of brain science, psychology, imaging, mathematics and computer science in research into the mind, consciousness, and mental illness**
- **integration of research on design with research on the human aspects of the use of technology, including the physical, psychological, team, organizational, and political (after Vicente)**

Theme 1. Integration ..... (cont'd)

Sustainable development

- simultaneous consideration of technological/economic, social, and environmental issues
- new context for energy and economics research, and likely to be increasingly connected to climate change research

Security

- "Security" writ large – integration of relevant disciplines in all the traditional areas of public safety and public health, with a new stress on prevention measures; antiterrorism; and reducing natural hazards to manageable risks
- will depend on success in learning how to "drink from a fire hose"

Integration .... (cont'd)

Molecular-scale phenomena

- convergence of the various approaches in the study of molecular behaviour and structure (e.g.: ultra-short laser pulses, X-ray crystallography, quantum computers solving the Schrödinger wave equation, etc.) when the scale comes down to the individual molecule, and the bulk properties of their aggregates in nature become irrelevant
- the inverse of the above – convergence of methods and concepts from various fields to learn how to combine the understanding of individual molecules to explain or predict the behaviour and properties of different aggregations of molecules in different settings

This is not meant to be a complete list, nor an exclusive one. There will be many more examples of important research that requires integration, some of which might eventually lead to the creation of new disciplines, as well as countless examples of important research within the existing disciplines that will require no integration at all.

Theme 2. “Drinking from a fire hose”

- The development and deployment of a profusion of new sensors, the automation of measurements and data collection, and the growing use of wireless communications in field research is producing a flood of data in many experimental fields: high-energy physics, astronomy, genomics, oceanography, seismology, structural engineering, etc., etc.

- The growing use of large-scale “in silico” simulations adds to this situation.

- Researchers trying to learn from the newly available data are faced with a challenge sometimes referred to as having to “drink from a fire hose” – the metaphor for making sense of a flood of measurements.

Theme 2. "Drinking from a fire hose" .... (cont'd)

- This trend has the potential to change "suitcase science" to "desktop science", but only if researchers develop arrangements for making their raw data available to all who might use them to test theories, calibrate models, etc.

- Research in many fields (e.g.: statistics, computer science, pattern recognition, visualization, quantum computing, grid computing, etc.) to develop methods and tools to extract useful information from the flood of data will grow in scale and scope.

- Important results have already been achieved in various fields (e.g.: high- energy physics, bioinformatics, meteorology, aerodynamics, etc.), but many methods and tools are particular to the fields of application; research to develop generic methods is the continuing challenge.

Theme 3. Modelling

- Science is expected to provide predictions for the real world, in much more complicated environments than controlled experiments.
- The most prominent example today is weather forecasting; others include the prediction of climate change and of earthquakes, and public policy dealing with natural resources and environment.
- Such predictions come from models incorporating measurements and observations in a mathematical structure based on the appropriate laws of nature, e.g.: the Navier-Stokes equations
- As experimental results accumulate and modelling tools improve, modelling will spread to more fields of research, e.g.: living systems, in which the living “model system” might begin to be replaced by a mathematical model.
- At the small end of the size spectrum, the model of the living cell would be an outstanding achievement that creates entirely new research capabilities.

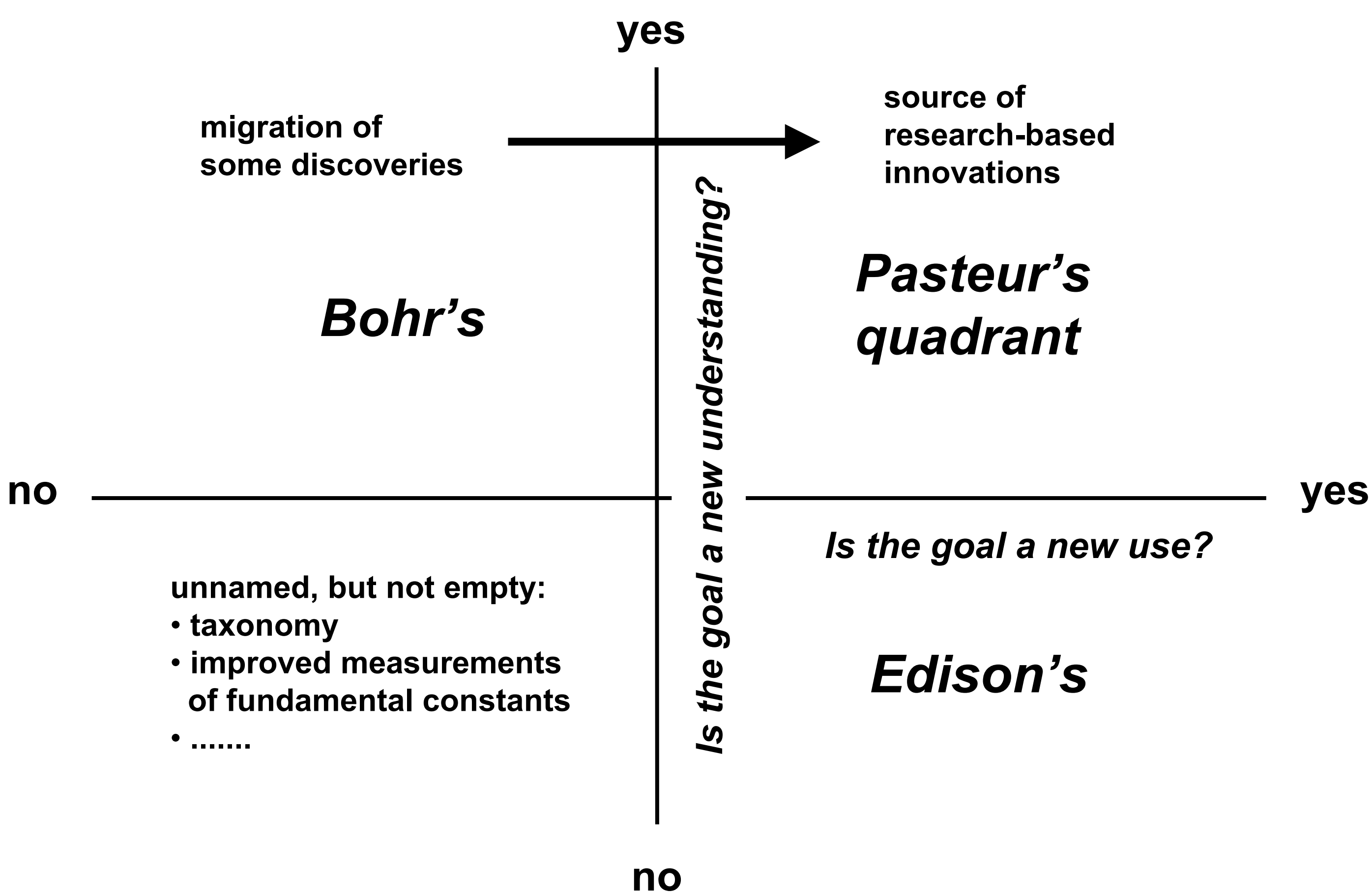
Theme 3. Modelling .... (cont'd)

- Most models require a great deal of computation (on multiple scales) to produce predictions - research will continue to improve their mathematical structure and the computing tools
- Models must be validated and calibrated, and there is always pressure to improve their precision (in both space and in time). Big advances in computers will make improvements possible.
- Advances in modelling and computation (e.g.: real-time computation incorporating field data into adaptive models) may help deal with the challenge of "drinking from a fire hose"
- The inclusion of new interactions in complex models is itself a force for integration, e.g.: ocean-atmosphere interactions in climate models bringing oceanography and atmospheric sciences together.

Theme 4. Institutional Innovation

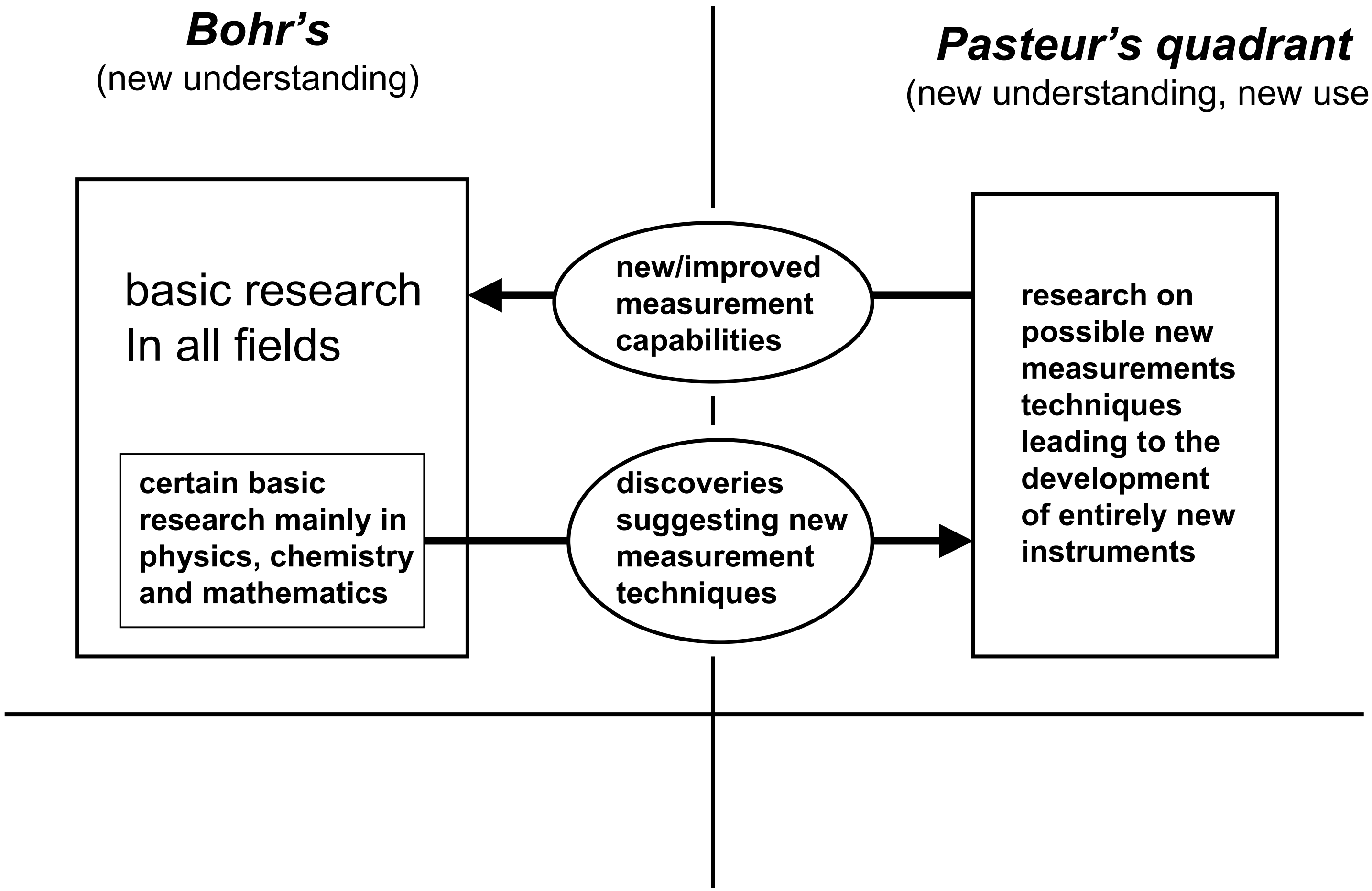
- Some of the new expectations of research will require new behaviours on the part of researchers, behaviours that are not always encouraged and rewarded by existing institutions for research support and evaluation.
- Dealing with this issue will challenge institutional innovation on the part of those who sponsor research and those who manage it.
- We can take it as given that Canadians can create and manage multidisciplinary research networks, but other challenges remain.
- For example, decisions on the support of risky research far ahead of today's advancing frontier of knowledge will still require the quality control provided by peer review, but may be inhibited by that assessment being made within the prevailing paradigm
- Three models of research organization combine to illustrate the challenges and the opportunities for institutional innovation in research support:
    - Pasteur's Quadrant
    - The "Swiss cheese" model of research, and
    - The "bifurcation" theory of research

The motivation for doing research – as described in "Pasteur's Quadrant"

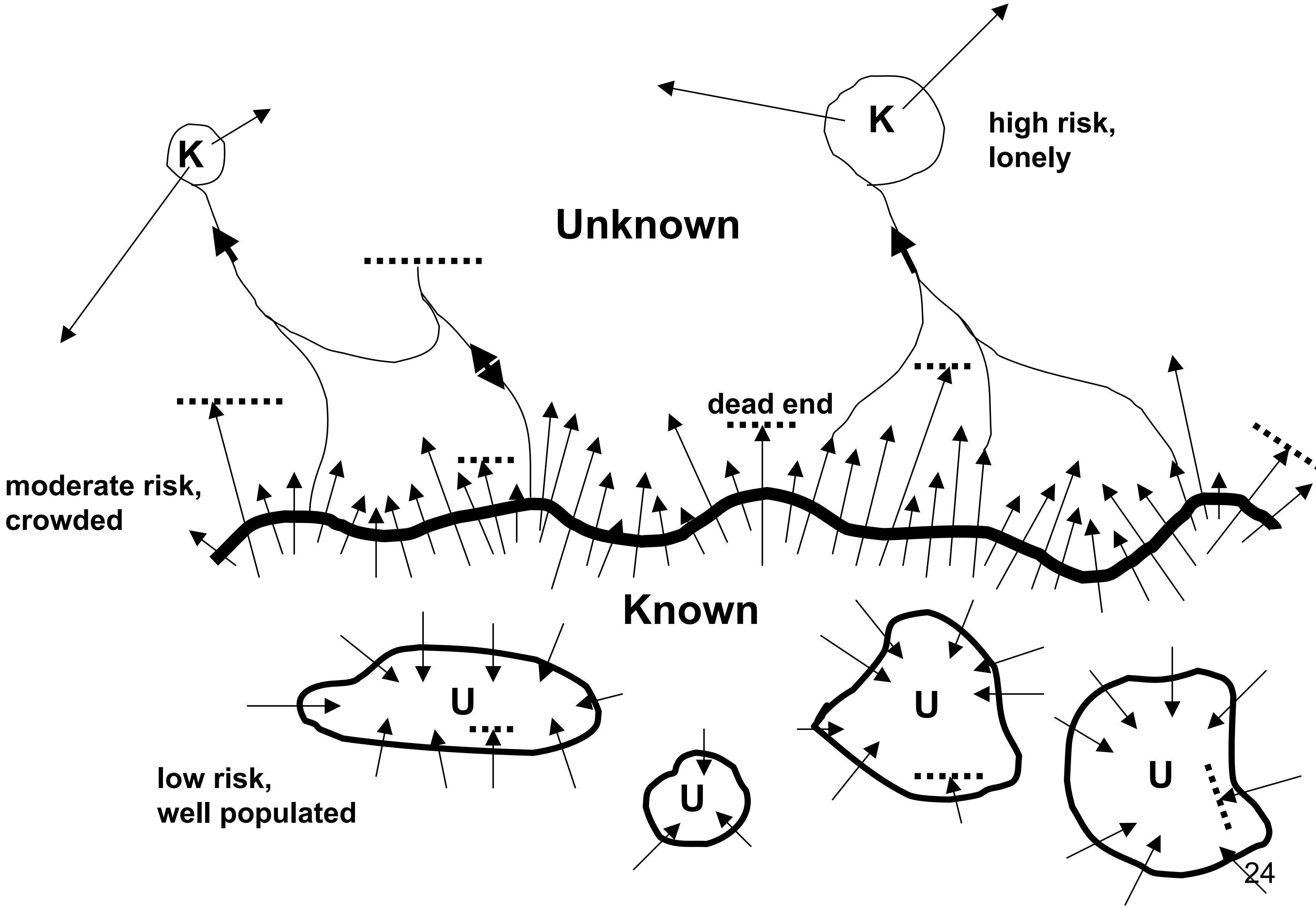


Source: D. Stokes, <u>Pasteur's Quadrant</u>, Brookings, 1997

One example: new principles of measurement



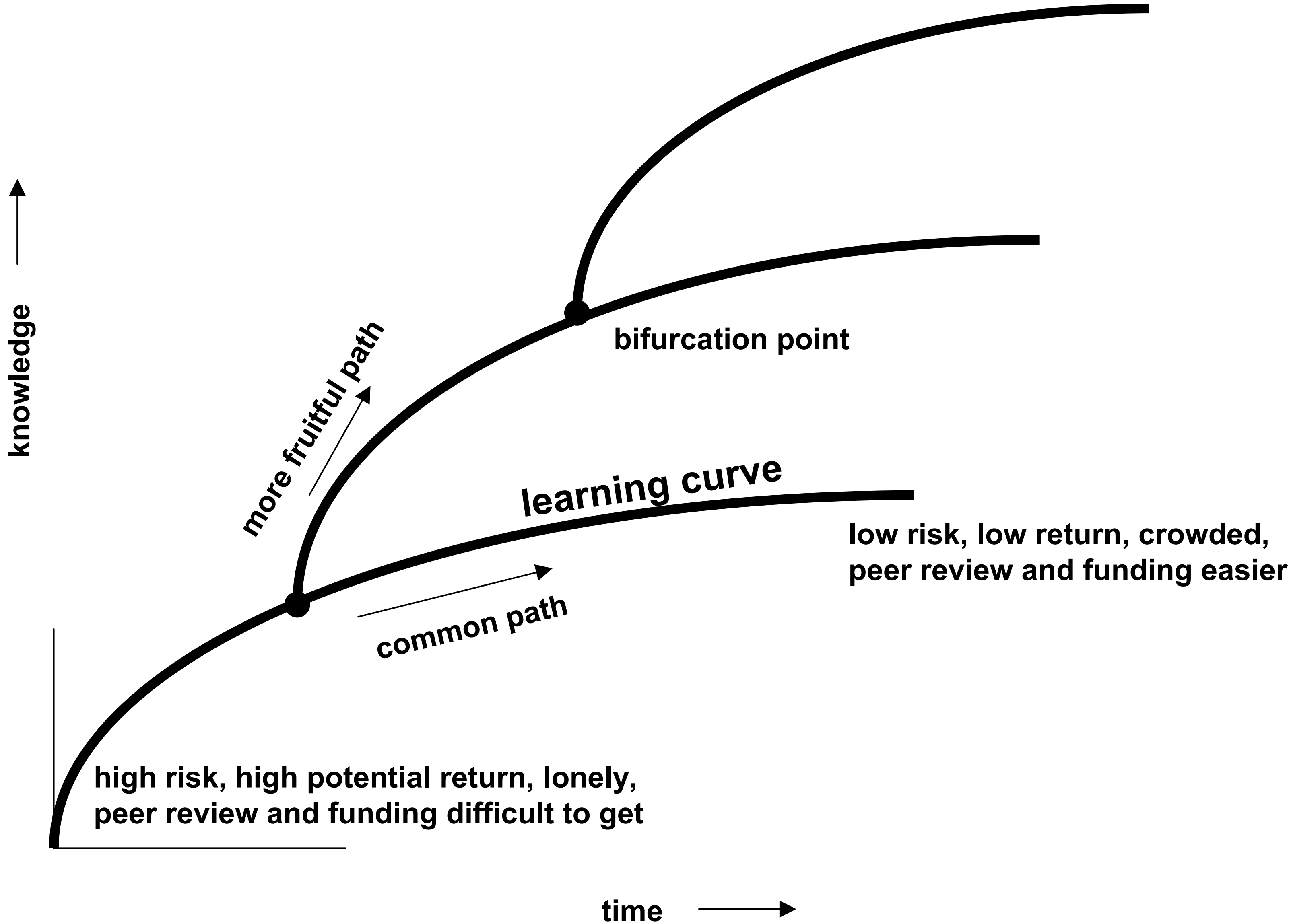
The “Swiss cheese” model of research



Lessons from the “Swiss cheese” model

- Risk here refers to scientific risk – the risk of not achieving the desired result even though the research is done very well.
- Peer review is supposed to weed out the risk of research being done badly.
- There are lots of peers available to assess work at the leading edge, as well as the research that would fill in gaps in knowledge behind the edge. But a word of caution : the leading edge isn’t absolute. e.g.: to a physicist, solving the Navier-Stokes equations of fluid mechanics in a new flow configuration might be gap-filling; to an aerodynamicist, it might be leading-edge research.
- Who can act as a peer reviewer of proposed research that would leap far in front of the leading edge? Innovation is needed to achieve the quality control of peer review, but also avoid the resistance of the established paradigm.
- Another needed innovation: publishing and giving credit for good research that leads to a dead end. Identifying dead ends might provide new knowledge; at the very least it will steer other researchers away from barren trails.

The bifurcation model of research



Lessons from the Bifurcation model

- The knowledge-time (K-t) curve, also known as the learning curve, is the trajectory for a given field of research – but it may also be the trajectory for the work of an individual researcher.
- The steep early part of the learning curve is risky and difficult, and sparsely populated by researchers; peer review is difficult, and funding hard to get, but successful research in that region can bring large scientific returns.
- The flat part of the learning curve is far better populated, peer review and funding are easier to get; good research there is much less risky, but it brings smaller returns.
- The challenge to research sponsors is to persuade good researchers to look for natural bifurcation points and go up new learning curves, in a system where it is far easier for everyone involved to continue on the flat part of the K-t curve.
- The best researchers readily obtain support to continue on the old learning curve where they already have momentum, but some then use the funds to branch to a new learning curve. Is that a ploy that should be ruled out, or is it an effective strategy - perhaps the only one - for developing new lines of research in the current funding system?

Theme 5: Commercialization and strategies for wealth creation

- **Wealth creation is the business of industry, and most industrial innovation (i.e.: the commercialization of new or improved goods and services) is the result of industrial R&D prompted by feedback from the market.**
- **Wealth is created when value is added, and knowledge is very often the main basis of added value in the modern economy.**
- **Thus university research is an essential adjunct to industrial R&D, both in creating knowledge and in educating the people who will use it.**
- **University *basic research* steadily builds up the foundations for revolutionary innovations, sometimes creating entirely new industries or sectors. Such innovations are rare and hard to predict, but can prove very important.**
- **University *project research* in partnership with industry solves problems that can't be solved with existing knowledge, and supplements industrial R&D in producing occasional radical innovations and many incremental innovations. Commercialization of the results is generally done by the industry partner.**

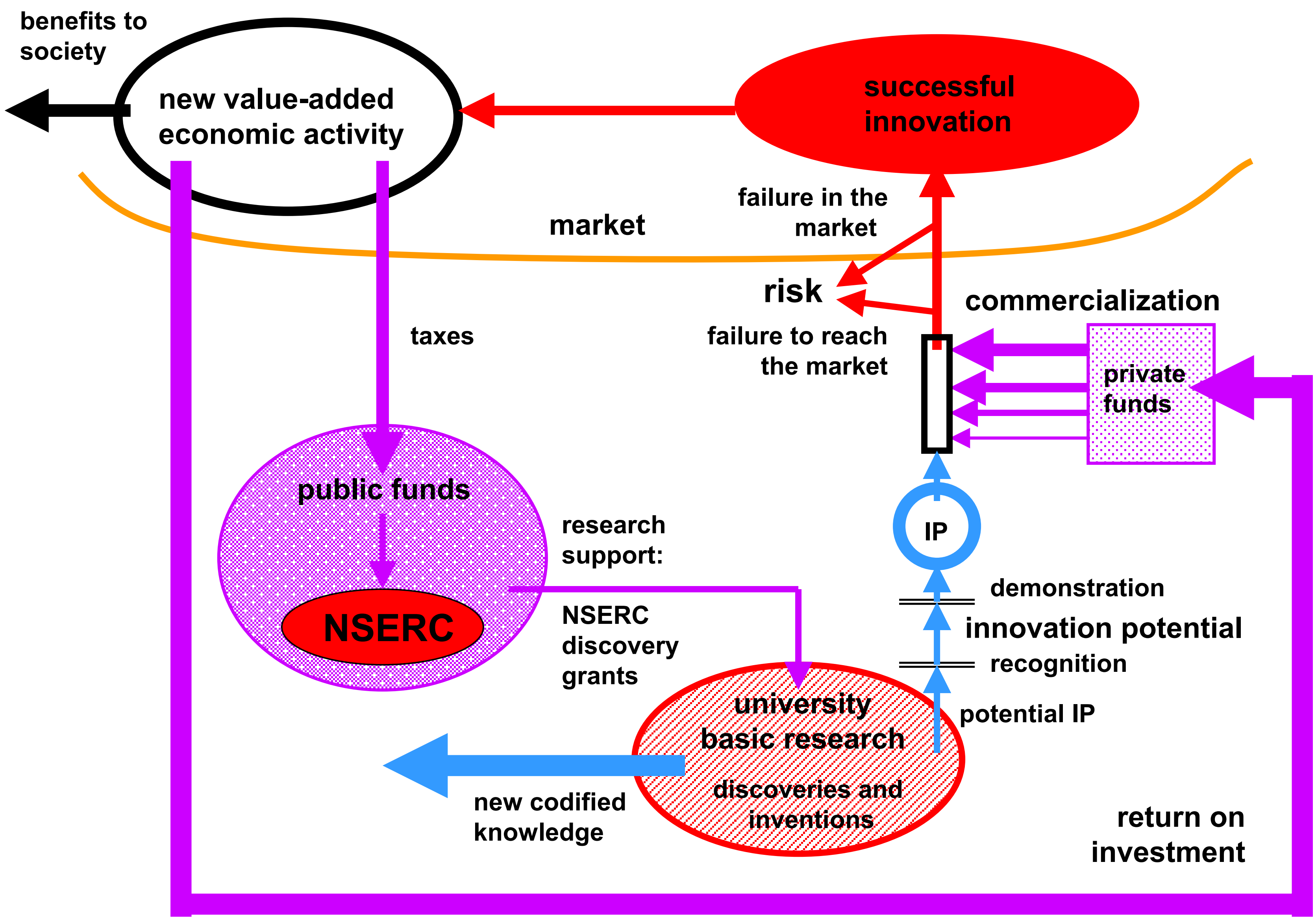
Commercialization and strategies for wealth creation......(cont'd)

- The commercialization of the results of basic research is difficult. There is no market pull; it's all technology push. But universities are learning how to do it, with good results.

- NSERC has documented the history of 134 first-generation companies that emerged from basic research supported by NSERC over the last two or three decades. All of that research was first undertaken with discovery as the only goal – in Bohr's quadrant. But when someone recognized that the results might have a new use, further work migrated to Pasteur's quadrant.

- The following diagram shows how the commercialization of the results of basic research in Canadian universities works when it works well. This is empirical and related to the above – somebody must recognize a possible use if a discovery in Bohr's quadrant is to lead to work in Pasteur's.

- The same diagram shows the bottlenecks and identifies the needs for institutional innovation.



Commercializing the results of university basic research

Lessons learned from the commercialization of the results of basic research

- The probability of a particular potential IP leading to a successful new product is very low, but not zero. In the case of successes, a small flow of public funding for basic research can catalyze a huge flow of private activity in the economy.

- The cost of commercializing a discovery or invention arising from basic research is generally very much greater than the cost of the research that produced it.

- The public funds supporting the research are exposed only to scientific risk; the private money invested in bringing a new product to market is exposed to commercial risk: the risk of failing to get to market, or failing in the market.

- Much of this applies also to project research, research started in Pasteur's quadrant with a possible use already in mind. Hundreds of Canadian companies have been partners with NSERC in supporting such work.

- When industry is involved as a partner, some market pull exists and the work is likely to lead to an incremental innovation, but much more predictably and quickly. Nevertheless, some university-industry partnerships develop into long-term relationships between researchers and producers that can also lead to radical product or process innovations.

Lessons learned ... (cont'd)

- Innovations based on university research can bring a large benefit to society by producing new value-added economic activity that pays wages, taxes, and a return on the private investment, and provides society with a new service or good. This can happen even if the direct return to the university is minimal, and the commercialization operation is a cost centre and not a profit centre.

- The alternative to commercializing Canadian university research results that have innovation potential for the benefit of Canada is to risk having to import foreign products based on discoveries made here – not just missing a chance to create new value-added economic activity in Canada, but paying for creating it in another country.

Peering into the next 25 years ....

- A lot of excellent research in science and engineering will be done in Canadian universities, much of it led by the people now being appointed.
- Canada's reputation for research will rise as Canadians make significant discoveries in many fields where world science is advancing.
- There will be a lot of institutional innovation in research funding to encourage a greater volume of risky and novel university research by teams of scholars from a variety of disciplines.
- Young people educated in the context of research evolving in this way will treat the integration of disciplines and approaches as routine, and will represent a new capacity of Canadian society to deal with new and complex problems in many areas.
- University research in partnership with industry will build up the receptor capacity of the Canadian economy for new knowledge and its innovative use, as the grad students educated in that context join industry.
- The capacity of university research to contribute more directly to innovation in the Canadian economy will grow as universities develop the capacity to commercialize research results in appropriate and effective fashion.