TORONTO REGION RESEARCH ALLIANCE

AT A CROSSROADS

STRENGTHENING THE TORONTO REGION'S RESEARCH AND INNOVATION ECONOMY

Lessons from leading high-tech centres around the world

This Toronto Region Research Alliance report was prepared by a team of researchers from the Program on Globalization and Regional Innovation Systems at the Munk Centre for International Studies, University of Toronto. The lead author is Tijs Creutzberg, PhD, with support from Professor David Wolfe, PhD and Jen Nelles (PhD candidate).

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PREFACE FROM THE TORONTO REGION RESEARCH ALLIANCE

Canada needs to act now to respond to national governments worldwide that are providing significant, predictable and growing investment in their R&D regions.

Aptly titled *At a Crossroads*, this report by a team of leading researchers at the Program on Globalization and Regional Innovation at the University of Toronto's Munk Centre for International Studies highlights the urgency and opportunity for the R&D economy of the broader Toronto region.

The Toronto Region Research Alliance (TRRA) is a not-for-profit catalytic organization dedicated to making the Toronto region one of the world's top 10 venues for research and research-driven industry. TRRA commissioned this study of world-leading R&D centres to better understand how they organized themselves to achieve success. Who did it? How did it happen? How long did it take? Are there any common factors?

Three of the conclusions are particularly noteworthy.

1. The Toronto region is globally competitive

The study confirms that Toronto and the surrounding area is a highly competitive, world-class regional R&D economy with strong research institutions, exceptional research talent and impressive industry clusters. With a population of almost seven million and a Gross Regional Product (GRP) of $255.6 billion US, it is home to North America's second-largest automotive and financial services clusters, the third-largest information technology and telecom equipment cluster and the fourth-largest pharmaceutical and biotechnology cluster. Its institutional research capacity is remarkable, with eight universities, ten colleges, 60 hospitals and 37 medical research institutes. The region performs 35% of all R&D in Canada, accounts for 33% of Canada's most highly cited scientists and is ranked second only to Boston in the number of science and engineering articles published.

2. Canada needs to act now to respond to national governments worldwide that are providing significant, predictable and growing investment in their R&D regions.

The study also finds that Canada's R&D regions are at an increasing disadvantage in today's competitive global R&D economy, where national governments are taking a much more proactive role by making transformational strategic investments in their regional R&D economies. Overwhelmingly, this is the key factor that is common to all of the regions surveyed in this report. In fact, in most of these countries, national investment in research and innovation is growing by leaps and bounds.

It is true that Canada has made enormous strides in the past decade — the Canada Foundation for Innovation, which has funded research infrastructure; Genome Canada, which has boot-strapped genetic research; CANARIE, a national high-bandwidth network for research; the Canada Research Chairs program, which has made the recruitment, repatriation and retention of major research talent possible. All have contributed to a real renaissance of research in Canada.

However, as profound as the improvements in national support for research have been, a number of these key agencies have either reached the end of their terms or have received no word as to their future funding. And, even with these investments, Canada's overall expenditure on R&D remains less than 2% of GDP and the Government of Canada's expenditure on R&D is less than 0.7% of GDP — in both cases, this ranks Canada lowest amongst the countries surveyed in this report and lower than the overall OECD average.

Contrast our situation in Canada with President Bush's announcement this year of the American Competitiveness Initiative, which doubles the US government's commitment to research and innovation by committing an overwhelming $136 billion US over 10 years.

Or Singapore's new five-year S&T Plan 2010 that will invest $13.5 billion US to strengthen its R&D capabilities in niche areas while nurturing and recruiting world-class talent.

Undoubtedly, Canada is at a crossroads. Will our national government choose to make the dramatic investments which will move us into the top tier of innovation-intensive countries in the world? Or will we be satisfied with the status quo, which will effectively mean falling behind in the international R&D arena?

3. The *regional mobilization* model offers most insights for Canadian R&D regions

This study finds that there are essentially three different models of regional R&D systems — *dirigiste*, *embedded* and *regional mobilization*. The research team concludes that the *regional mobilization* model would be most appropriate for Canada. In this model, the national government provides sustained and predictable funding but leaves much of the strategic decision-making to local organizations and regional leaders who will collaboratively invest those resources to grow the strategically important clusters in their regions.

TRRA will be analyzing in detail all of the report's conclusions to understand how best to apply them to our mission in the broader Toronto region. We offer this report as one contribution to the growing Canadian dialogue on these important issues as we await the release of Industry Canada's new Science and Technology Strategy.

We believe this study provides important insights for governments and all sectors of the R&D community in Canada. TRRA and our partners are eager to engage in the national debate on the future of research and innovation in this country and we look forward to working collaboratively with other regions in that regard. We believe nothing less than Canada's future depends on it.

Ross McGregor
President and CEO

Toronto Region Research Alliance

EXECUTIVE SUMMARY

KEY FINDINGS

- The most common factor shared by successful regional innovation systems is significant, strategic public investment
- Levels of national investment are increasing in size and sophistication
- There are different models of regional funding but the most applicable to Toronto region is one of *regional mobilization*

This study identifies common factors that have influenced the development of the world's most successful research and innovation centres. It does so from an analysis of six leading regions throughout the world, with the purpose of drawing out lessons that are applicable to the Toronto region's efforts to become an equal to the very best of these centres. There are three key findings that deserve particular attention.

First, the most common factor shared by all leading centres is the very significant levels of strategic public investment, be it in universities, research laboratories or through national technology programs. Governments today, far from leaving their capabilities to develop through market forces alone, are becoming increasingly sophisticated at combining and concentrating national resources with local research and knowledge strengths to take advantage of opportunities resulting from market forces and trends in technology. And in the process, countries and regions are successfully capturing the related economic benefits of high-tech industries within their borders.

Second, this study finds that the level of national investments made in support of research and innovation in key industries is on the increase. The United States, in particular, has made several significant investments in recent years in areas such as nanotechnology and high-end computing, all with stated goals of developing a competitive industrial capacity. In the context of these strategic investments, it is readily apparent that Canada is not competing at the same level relative to the size of its economy. And given the lag between investments in research and economic development, the impact of this underinvestment will undoubtedly be felt in the future. This is especially so for Canada's leading research and innovation centres such as the Toronto region, whose firms are increasingly dependent on public research infrastructure for their competitiveness.

The third key finding is that there are important differences in the way in which national investments are channelled into regional knowledge-based economies. Three such models are identified in this study, all of which have important lessons for the Toronto region. The most relevant, however, is the *regional mobilization* model, best represented by the development of Austin, Texas and Raleigh-Durham, N.C. This model highlights the importance of regionally mobilizing and coordinating local resources, such as universities, firms, money and talent, to leverage additional research investment from upper levels of government and attract firms, so as to develop a globally competitive research and innovation capacity.

For this approach to work, however, government must provide the flexibility in their support for R&D such that regions across the country can draw down R&D funding according to their own investment needs. Be it for a new research institute, specialized training programs, or to attract a major R&D firm that complements local industry strengths, such tailoring of investments to local needs will prove crucial to sustaining a foothold in rapidly changing global technology markets.

This approach would likely benefit not just the Toronto region but also all of Canada's centres of research and innovation, as well as the country's less developed urban regions. Exposed to the dynamics of a global knowledge economy, leading regions require the flexibility to help adapt their local economies and knowledge infrastructure to the ever-changing technology markets. The *regional mobilization* model of strategic investment can help facilitate this process. For less developed regions, it can offer important flexibility and resources to guide their own economic development according to their own aspirations and local strengths.

INTRODUCTION

> "Groundbreaking ideas generated by innovative minds in the private and public sectors have paid enormous dividends – improving the lives and livelihoods of generations of Americans."

– US President George W. Bush, preface to American Competitiveness Initiative: Leading the World in Innovation (Feb. 2006)

Recognizing that its future prosperity in a global economy will increasingly depend on its competitive advantage in science and technology, the Toronto region has set itself the goal of becoming a world-leading centre for research and innovation. And for good reason. Advanced technology industries are driving an ever-growing share of economic activity — not only in the region, which has become a megacentre in life sciences and ICT, but also in Canada and abroad.[1,2] By most accounts, this trend is likely to continue unabated as innovations continue to create new markets and new opportunities for employment. One estimate puts the global forecasted revenues of nano-based technologies alone at more than $3 trillion US within a decade — creating two million jobs in the process — and providing an economic impetus that is expected to drive the world economy for the next 50 years.[3]

With these economic prospects, the Toronto region is resolved to becoming a successful competitor to the world's premier technology centres. To this end, this study examines six leading and several emerging city-regions, all of whom have built up, or are in the process of building, a regional research and industrial capacity to enable their firms to successfully compete in the same global technology markets as do many of the Toronto region's leading-edge technology firms. The purpose is to understand what common factors, if any, account for their success in research and innovation. Specifically, the key questions are: what conditions have contributed to the success of science- and technology-based economic development in leading technology centres; and what lessons can be derived from these centres that can help the Toronto region achieve its stated goal of being an equal to the very best research and innovation regions of the world?

The six leading centres examined in this study are: Austin, Texas, Boston, Mass., Raleigh, N.C., San Diego, Calif., Singapore and Stockholm.[4] These case studies are complemented by an overview of three emerging centres: Bangalore, Shanghai and Albany, N.Y. All were selected on the basis of their established and emerging strengths in the same advanced technology industries that are prominent in the Toronto region — biosciences, ICT, materials, nanotechnology and advanced manufacturing. And while the regions are by no means equals in any one industry, they each have a competitive research and industrial infrastructure that has either attracted a notable number of research intensive firms or has enabled existing firms to build a strong global presence in leading technology markets.

This study has used the city-region as a unit of analysis to account for the fact that this regional level has become the focal point of global competitiveness and innovation. The broader national R&D system does, however, continue to play an important role in shaping the research and innovation economy at the regional level. To account for this, the study develops a framework to clarify differences in how national investments are channelled to urban regions.

The report begins with a review of the key challenges faced by firms, governments and city-regions alike when competing in rapidly changing global technology markets. This provides the context for understanding the framework used in analyzing six leading research and innovation centres from across the world, which highlight the key factors in their development. Last is an analysis of the Toronto region's research and innovation capacity and an assessment of the region's effectiveness at securing the necessary public investments to keep its knowledge infrastructure globally competitive.

EXPLOITING THE POTENTIAL OF A KNOWLEDGE ECONOMY: CHALLENGES AND OPPORTUNITIES

"I don't think that a high standard of living is an entitlement...If Indians and Chinese can work 80-100 hours a week and they are part of a global, fungible labour market, it's going to have an impact on living standards in the west."

– Nandan Nilekani, CEO Infosys, India's top IT company[5]

For all of Toronto's existing strength in research and knowledge infrastructure that support its high-technology economy, there is no assurance that the Toronto region will achieve its goal of becoming a leading centre for research and innovation. In addition to the intense global competition by firms and governments alike to capture the economic benefits of advanced technology industries, the very nature of these innovation-driven industries makes their future unpredictable.

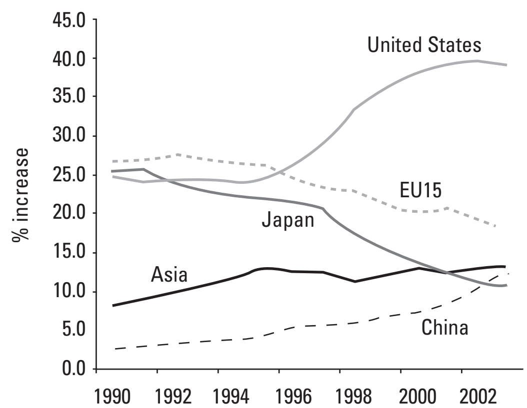
Just as new innovations can create many opportunities for employment and efficiency growth, they can also disrupt, if not wipe out, existing markets for technologies and methods of production, with considerable consequences for the firms and the employees that produce them. As the computer industry has demonstrated, products derived from major technological advances can become low-priced commodities in as little as a decade, whose production and development is then off-shored to lower-cost regions.

From a geographic standpoint, new innovations and advances in knowledge can therefore shift the economic fortunes of not only firms and industries, but entire regions and countries, in a relatively short time span. This dynamic will become all the more pronounced as China and India reach their full potential in the global R&D system. China is already the third-largest performer of R&D, behind only the US and Japan, having registered 24% average annual increases in R&D expenditures over the past five years. The country has also made significant gains of late in high-technology manufacturing. This is in strong contrast to Japan and Europe, which have both experienced a marked decrease in output between 1990 and 2003 (Figure 1).

In this competitive environment, high technology firms are faced with the daunting challenge of constantly learning and innovating so as to maintain access to the ever-moving frontier of knowledge and technology. Investing in R&D, accessing new knowledge through collaborations with firms and research institutions, and attracting highly skilled people are activities that are now essential to the business development strategies of these firms. In fact, to achieve this learning, firms will often establish a presence in, or relocate entirely to, regions where the relevant knowledge is located.

Figure 1: Shifting fortunes

Location of world's high-technology manufacturing output, 1990-2003



Source: Science and Engineering Indicators, 2006

Role of government

The challenge for governments in this competitive climate is equally great. As firms become more dependent on public research infrastructure, governments are under pressure to maintain, if not increase, support so as to sustain their economic competitiveness. Without continued investment in the R&D infrastructure of its economic regions, countries risk losing whatever wealth they may derive from these high-growth and high-wage industries as high-tech activity shifts to regions with more advanced research infrastructure. For many governments, who generally consider their success as a nation to be defined by their relative success in these industries, this is not a risk worth taking.[6] Thus, as more and more countries seek to establish a foothold in these industries, the imperative to invest becomes even stronger. To stand still in these industries is — as many governments now understand — tantamount to moving backwards.

The resulting sense of urgency is readily apparent from the sheer number of strategic investment initiatives by national and provincial governments the world over. Public investments in the order of hundreds of millions of dollars are being made in research infrastructure, typically with the expectation that these investments will provide a return in the form of high-growth, high-wage industries, as well as ready domestic access to, and knowledge of, the critical technologies of the future. It is estimated that in the US alone, some forty states are targeting the bioscience industries with significant investments, with many focusing strategically on particular niches.[7]

Role of city-regions

City-regions, for their part, are also taking up the challenge for two main reasons. First, under pressures from globalization, rapid technological change and the downloading of programming by upper levels of government, city-regions have become more exposed to — and more responsible for — the vagaries and uncertainty of external market forces. And second, knowledge-based industries tend to cluster in city-regions with ever-larger concentrations of research intensive institutions, which are sometimes referred to as 'research megacentres'. Silicon Valley's success in the ICT industry is undoubtedly the most famous example of this clustering effect, having become a household name for regional economic success the world over. There are, however, many others notable examples: Austin, Texas has become a major centre for microelectronics; San Diego, Boston and Stockholm, Sweden for biosciences; and recently, Bangalore for ICT. A 2002 study of biotechnology in 51 US metropolitan centres emphasizes just how significant this concentration can be. The authors found that the top biotechnology centres have almost nine times as much biotech research activity and 20 times the amount of commercialization activity than average.[8]

The new locally influenced industrial policy

In response to these trends, several high-tech regions, particularly in North America, have come to play an active role in shaping and supporting the development of their knowledge-based industries. Through collaborations between local leaders and various levels of government, regions have been recasting the basic foundations of traditional national industrial policy. By acting strategically in coordinating local resources and drawing upon financing from upper levels of government, many regions are successfully building a highly competitive research capacity to support and develop targeted knowledge-based industries. This is being supported by aggressive efforts at the regional level to strategically recruit and retain firms that complement existing strengths in industry clusters. In order to accomplish this, however, competitive city-regions must be able to rely upon ready assistance from senior levels of government.

Shanghai – Emerging ICT Hotspot

In recent years, the most significant public investment in ICT capability has come from Asian states, which have been very successful at breaking into integrated circuit (IC) production. Indeed, the top IC manufacturers — UMC and TSMC of Taiwan — each initially had substantial government backing and support that ultimately reshaped the entire global production model for IC chips. As of 2003, these two firms accounted for $8.6 billion US in revenues.[58]

The Chinese government has also just recently entered the semiconductor market, having backed the creation of SMIC in 2000, located in Shanghai. SMIC, now the fourth-largest dedicated 'pure play' IC manufacturer in the world, consolidates government efforts that began in the late 1990s to establish Shanghai as a centre for semiconductors. The efforts involved a $1.2 billion US investment in the largest-ever project undertaken in China's electronics sector, with the expectation of building up an industrial capacity in integrated circuits in the Shanghai region.[59] The region now boasts some 27 IC manufacturers, 238 design companies and 88 package and assembly companies, with total sales revenues of over $4.5 billion US. The government has recently said it plans to cultivate no fewer than 40,000 IC designers and 10,000 IC processing technologists over the next six to eight years.[60]

NATIONAL R&D SYSTEMS

A COMPARATIVE LOOK AT FOUR NATIONAL R&D SYSTEMS

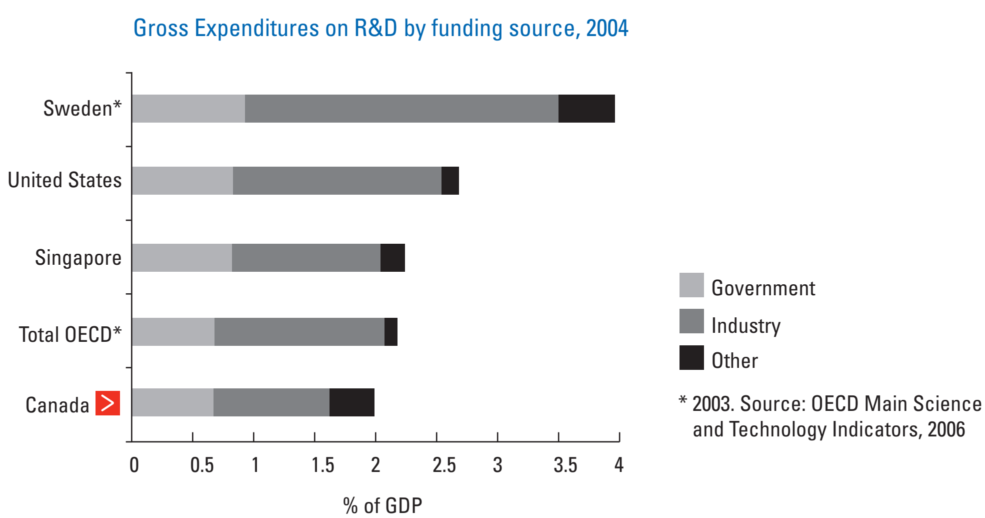
Canada, having committed just less than 2% of GDP on R&D, ranks the lowest among the countries in this study and marginally lower than the OECD average.

The national governments of the six leading urban regions reviewed in this study all have well established roles in supporting research and innovation. This support, however, varies considerably in extent. As Figure 2 reveals, Sweden has the highest expenditures on R&D as a percentage of GDP, not just among the countries in this study but also among OECD members. The amount that the government spends on R&D is also the highest in the group, reflecting levels of investment in education that are among the highest in the world relative to the size of its economy. In absolute terms, however, the United States government is the single largest supporter of R&D in the world, having committed some $137 billion US to R&D for FY 2007. This amount contributes to a total gross expenditure on R&D of $318 billion US or 2.7% of GDP. Canada, having committed just less than 2% of GDP on R&D, ranks the lowest among the countries in this study and marginally lower than the OECD average.[9]

There is also a great deal of variation in who performs a country's R&D, reflecting in part structural differences in respective national R&D systems. Industry, for example, accounts for a far smaller portion of R&D expenditures in Canada (56% of GERD) as compared to Sweden (74%) or the US (70%).[10] In contrast, the higher education sector is a much more important R&D performer in Canada (34%), than in the US (14%) or Sweden (22%).

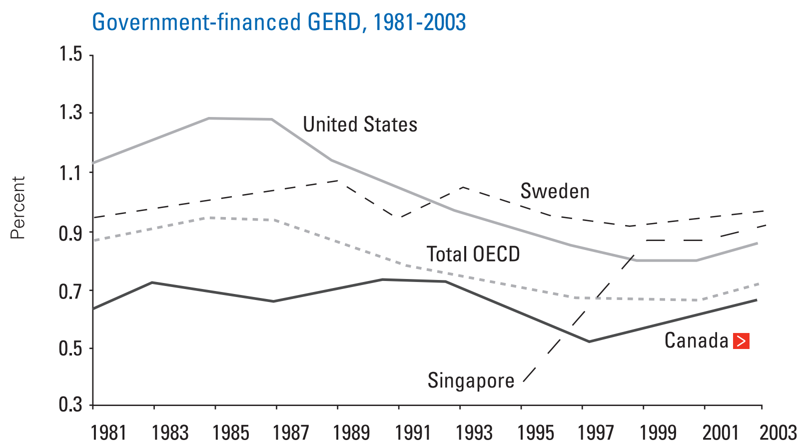
Differences aside, national governments in the past few years have shown a marked commitment to revitalizing their R&D systems. As Figure 3 shows, government-financed R&D has been rising in each of the countries reviewed, with the strongest growth coming from the US and Singapore. In the US, this reflects several recent multi-year initiatives aimed at developing research and industrial capacity in promising technologies, including the National Nanotechnology Initiative ($6.7 billion US since 2001) and the Advanced Energy Initiative ($10 billion US since 2001). Most recently, the US has announced a 10-year, $136 billion 'American Competitiveness Initiative' aimed at doubling the government's commitment to critical basic research programs in physical sciences. Similarly, Singapore has spent $6 billion US since 2001 through its S&T Plan 2005, strengthening R&D capabilities in niche areas and nurturing and recruiting talent. According to the government's new five-year S&T Plan 2010, Singapore will commit another $13.5 billion US over five years, with the stated goal of doubling the jobs in life sciences, environmental and water technologies and digital media by 2015.

Figure 2: Comparative snapshot of gross expenditures on R&D (GERD), by country



Canada has also shown a recent upswing in government-financed R&D, beginning in 1997 when the government committed itself to reinvesting in higher education. Since then, funding for higher education research has risen from $747 million Cdn in 1997-98 to $2.7 billion in 2004. A significant portion of this increase stems from several new programs including the Canadian Foundation for Innovation (est. 1997), the Canada Research Chairs Program (2000) and Genome Canada (2001), which together have received $5.0 billion Cdn between 1997 and 2005.[11] Despite this increase in funding, however, government-financed R&D in Canada continues to lag behind the other countries. Indeed, since the commitment to reinvest in higher education research, there have been few new initiatives supporting the country's R&D system. Moreover, as of 2006, both CFI and Genome Canada have essentially committed all their allocated resources and no government commitments have yet been made to further their funding.

Figure 3: National commitments to R&D



Source: Science and Engineering Indicators, 2006

Albany- Emerging Nanotechnology Hotspot

Though not yet recognized as a high-technology centre, Albany, N.Y. is a very strong contender to become one of the world's leading centres in nanotechnology. The State of New York, through its Albany Nanotech program[61], has committed over $500 million to semiconductor fabrication facilities at the State University of New York at Albany (SUNY-Albany) and to research and education programs at both SUNY-Albany and the region's Rensselaer Polytechnic Institute.

This investment has already begun to pay off, having triggered matching commitments from IBM, Tokyo Electron and Sony, as well as SEMATECH. In 2003, Austin-based SEMATECH announced that it would establish a facility in Albany to take advantage of the Albany Nanotech complex, much to the concern of Austin. And in June 2006, it was reported that AMD was in talks with state officials to build a $3.5 billion chip plant that could receive more than $1 billion in incentives.[62]

Once these investments establish themselves, Albany will be well positioned to take advantage of the federal government's multibillion dollar National Nanotechnology Initiative. This program, which has disbursed some $6.5 billion US since 2001, funds leading research, creates multidisciplinary centres of excellence and develops research infrastructure. The initiative also allocates funds to academic institutions, departments and agencies and to R&D contracts. Through the Small Business Innovation Research (SBIR) program, small technology firms receive 2.5% of all funds for competitive R&D contracts.

REGIONAL R&D SYSTEMS

THREE MODELS OF STRATEGIC INVESTMENT IN CITY-REGIONS

To account for differences in political systems that arise when comparing sub-national regions across countries, this study identifies important variations in the way in which regions interface with national governments in strategically developing their regional R&D infrastructure. The following section explains the structure of this framework, relevant as it is to drawing out lessons for the Toronto region.

Typically, advanced technology industries within a given region are publicly supported by two mechanisms. The first is the nation-wide R&D system, which includes, for example, tax incentives for innovation, funding for university-based research and other nationally oriented R&D institutions. The second mechanism comprises the strategic research and innovation investments, which are typically region- or industry-specific. These may include initiatives that establish a new specialized research institute in nanotechnology, as well as industry support or procurement programs aimed at developing industrial capacity in a targeted technology field such as advanced manufacturing.

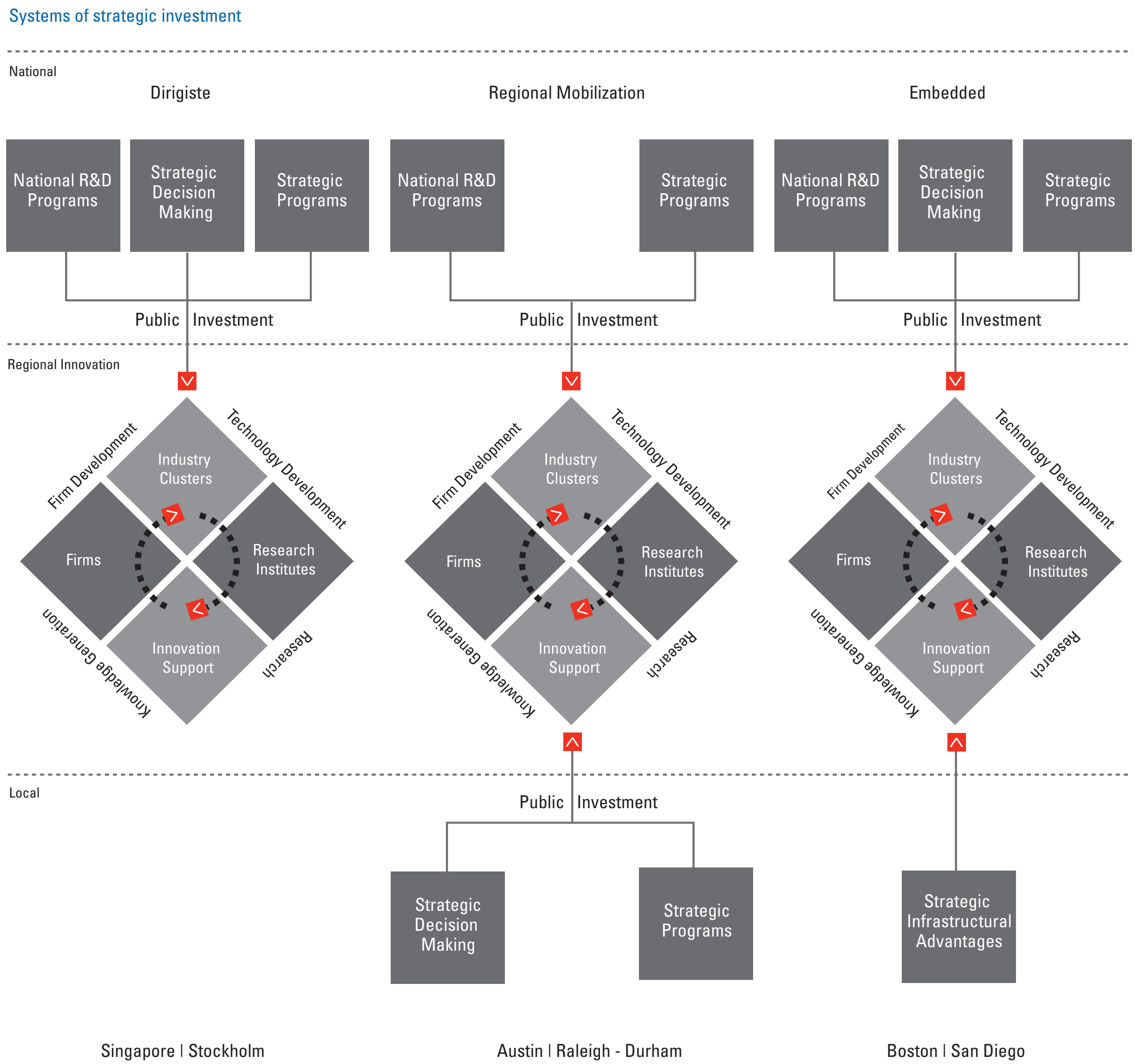
One of the major differences among national R&D systems relates to this second aspect, that of strategic public investments, an aspect that directly affects a region's efforts at science- and technology-based economic development. In particular, the way in which national governments decide which strategic investments to make, and where they are best directed, varies in important ways, which ultimately impact upon the role that a government has in supporting regional research and innovation infrastructure. The US government, for example, is a significant strategic investor in public R&D but typically does not concern itself with where these investments ultimately end up. National governments in Asia, however, typically do decide which regions and industries to invest in. To account for these differences in government R&D roles, this study groups the cases according to how decisions for channelling national investments in particular regions, and specific sectors, are made. On this criteria, regions fall into one of three categories (Figure 4).

The first type is *dirigiste*, whereby the national government plays a strong strategic role in channelling investment to the research capacity of particular regions. In this system, the national government provides both the public investment and strategic decision-making which determines which industries and regions are targeted and how. Of the regions reviewed, Singapore and Stockholm are characterized by the *dirigiste* system of strategic investment, with Singapore being the stronger of the two.

Second is the *regional mobilization* model, whereby the national government provides the resources but leaves the strategic decision-making to the local level. This model responds to the growing sophistication among many local governments and civic leaders in North America at mobilizing and leveraging resources at the local and national levels to strategically shape the development of local research-intensive economic activity. In effect, this local mobilizing element strategically enhances and organizes national and state investments and mobilizes local knowledge resources, such as universities, to build a competitive advantage in targeted sectors. Regions with a strong local organizing component are often less visible through international comparisons, despite the considerable level of state and federal investments that support these systems. Indeed, many of the high-technology regions that emerged in the 1980s, including Austin and Raleigh-Durham, have benefited considerably from local action in charting a strategic direction in the knowledge economy.

The third type, known as the *embedded* model, consists of those regions with a long-established and well-developed research infrastructure. By virtue of their size, quality or depth of labour pool, these regions are able to draw in a disproportionate share of investments, both public and private, to maintain and help adapt their knowledge-based sectors. These regions, such as Boston and San Diego, have, in effect, an embedded competitive advantage in research and innovation. In each case, however, the capabilities and infrastructure were originally created, and subsequently sustained, by major federal investments concerned with national security. Their systems of strategic investment are thus more in line with national S&T objectives and typically less strategically organized at the regional level. Given the sheer amount of public and private money invested on an annual basis, these regions often have the largest and most dynamic knowledge-based industry clusters.

Figure 4: Three models of strategic public investment



"For countries in the increasingly competitive and connected global world of today, sustained growth is only possible if stronger alliances and networks are forged; greater focus is placed on developing core competencies like innovation and technology; and a supportive business environment is fostered."

– Speech by Singapore's President, SR Nathan, July 26, 2006

Singapore

QUICK FACTS	
POPULATION:	4,351,400
GRP:	$116.7 BILLION US
GEOGRAPHIC SPAN:	SINGAPORE
USTPO PATENT APPLICATIONS:	848
SCIENTIFIC JOURNAL OUTPUT:	7,108
STAR SCIENTISTS:	4
MAJOR PUBLIC RESEARCH INSTITUTIONS:	7
VENTURE CAPITAL:	N/A
AVERAGE TECHNOLOGY WAGE:	N/A

* See Appendix B for sources

Case study highlights

The Singapore case is an important example of how competitive advantage in advanced technologies can be created. The government has made a long-term commitment to strategically create national resources in research and knowledge, in order to take advantage of market force opportunities and trends in technology. This policy approach is the antithesis of the laissez-faire economic development approach that influences many Western governments and offers an important perspective for aspiring research and innovation centres.

Dirigiste system of strategic investment in Singapore

Singapore is unique among the regions surveyed, not least because of its status as a city-state. With no natural resource base or agriculture sector to depend upon for employment, Singapore has been adept over the last four decades at creating competitive advantages in key technology industries, from petrochemicals to electronics and ICT, and now biotechnology.[12] Behind this successful capacity building have been several ambitious — if not aggressive — policies and several high-risk investments that have addressed the critical factors supporting knowledge intensive sectors, namely knowledge generation, research infrastructure, workforce development and venture financing.

All these policy elements have come together in Singapore's latest long-term quest to build a biotechnology cluster. With the goal of being Asia's 'premier hub for biomedical sciences', the government has been steadily investing in research infrastructure since 1987, establishing four new research institutions since 1996 alone. These new centres – the Bioinformatics Center, the Genome Institute of Singapore, the Bioprocessing Technology Centre and the Institute of Bioengineering and Nanotechnology — will have received a total of $1.5 billion US in investment come the end of 2006.[13]

Complementing these investments has been a talent recruitment strategy which has thus far drawn a Nobel Prize winner, a former director of the US National Cancer Institute and a first-rate cancer researcher from Japan, all of whom have been offered generous financial packages and research labs. And to bolster this knowledge building effort, the government is supporting Singaporeans to train at leading international universities and encouraging the country's research institutions to develop alliances with top biotechnology centres around the world.

One of the more remarkable components of Singapore's biotechnology strategy, however, is an additional $2 billion US set aside to support industry capacity development. The government has committed half of this amount to three venture funds supporting the city-state's biotech start-ups and to providing incentives for recruiting multinationals. The remaining $1 billion has been set aside to attract three to five world-class corporate centres of research.[14]

Biotechnology is by no means the first to have received such aggressive strategic assistance. In fact, these kinds of policies have also been at the core of its successful efforts in establishing itself as a centre for semiconductor manufacturing. In the early 1990s, for example, the government played a major role in financing the establishment of CSM (Chartered Semiconductor Manufacturing). CSM is now the third-largest contract manufacturer of IC chips in the world with a 2004 growth rate of 49% from the year prior. To further support the sector, the government designated it as a priority industry, which entitles firms to very low tax rates (from 0% to 13%) with the former rate applied to any chip manufacturer employing the most advanced technology.[15]

Finally, to address the growing demands for skilled labour, the government established an 'extremely liberal immigration policy' to assist in recruiting talent for the industry and launched the International Manpower Program to 'scour foreign universities for talent'.[16] CSM itself recruited some 750 people through this program between 1995 and 2000.

Stockholm

QUICK FACTS	
POPULATION:	2,968,000
GRP:	$123.6 BILLION US
GEOGRAPHIC SPAN:	STOCKHOLM UPPSALA
USTPO PATENT APPLICATIONS:	251
SCIENTIFIC JOURNAL OUTPUT:	7,007
STAR SCIENTISTS:	28
MAJOR PUBLIC RESEARCH INSTITUTIONS:	12
VENTURE CAPITAL:	$242 MILLION US*
AVERAGE TECHNOLOGY WAGE:	N/A

* Life sciences for Sweden as a whole – though mostly in Stockholm-Uppsala (source: Stockholm Business Region)

Case study highlights

Stockholm, as with Singapore, has benefited from a national government dedicated to directing investments to its knowledge-based industries within specific regions and to assisting with capital requirements of technology oriented firms. It offers a good example of a Western country, which typically are less interventionist than their Asian counterparts, committing public funds to strategically address serious market failures in the innovation system.

Dirigiste system of strategic investment in Stockholm

That Stockholm finds itself in the global spotlight for science excellence each year with the awarding of the Nobel Prize befits a city whose R&D capacity is among the world's best. Home to such R&D-intensive multinationals as Erickson and AstraZeneca and to the country's top universities — including the Karolinska Institute, Stockholm University, the Royal Institute of Technology and Uppsala University — the region is the main contributor to Sweden's status as the world's top per capita investor in R&D.

Stockholm's strength in technology-based industries, notably IT and biosciences, mirrors the country's long-standing economic prosperity. Indeed, over the last three decades the country has been a model of how to balance high rates of growth and social equity while sustaining large globally competitive technology firms. Through heavy taxation of personal income and consumption, the government has been able to tax capital income and profits lightly, helping direct capital and labour resources into Sweden's large globally competitive technology industries and ultimately promoting employment.[17] Stockholm's prominent multinationals have been major benefactors of this policy environment.

In an effort to ensure continued economic strength, at a time when there is growing evidence of offshoring of production and commercialization[18], the government has taken several steps over the past few years to strengthen research and innovation in the regions. In the mid 1990s, for example, the government funded 28 Competence Centres at eight universities, many of which are based in Stockholm. And in 2001, it established a new agency for innovation, VINNOVA, which now plays a critical role in setting strategic priorities and directing resources to support regional strengths in knowledge-based sectors.

These regionalized efforts mark a major shift in economic development policy away from supporting national industrial manufacturing and sparsely populated regions, to one focused on supporting regional strengths. Under what it calls Regional Growth Programmes, policies are guided by regional strategic action plans, which focus on building knowledge resources within regions, ensuring the supply of qualified workers and enhancing strategic cooperation between firms and universities.

Most recently, the government created the 'Innovation Bridge' for pre-commercial venture capital, which allocates $245 million US to knowledge-based innovations and early-phase startups. This program, which has two of its seven regional offices in the Stockholm region, builds on a much larger government VC fund called Industrifonden, which is a major venture capital investor in advanced technology firms in ICT, life sciences and energy. Currently, this government fund has approximately $436 million US in equity with investment capital of $218 million US. The fund also supports venture capital companies, including those with a regional focus, as well as seed capital firms linked to the universities and institutes of technology.[19]

Austin

QUICK FACTS	
POPULATION:	1,349,291
GRP:	N/A
GEOGRAPHIC SPAN:	AUSTIN ROUND ROCK SAN MARCOS
USTPO PATENT APPLICATIONS:	3,188
SCIENTIFIC JOURNAL OUTPUT:	3,659
STAR SCIENTISTS:	29
MAJOR PUBLIC RESEARCH INSTITUTIONS:	2
VENTURE CAPITAL:	[# DEALS/TOTAL] 80 / $459 MILLION US
AVERAGE TECHNOLOGY WAGE:	$45,731 US

"What people need to understand is that if you stand still in the semiconductor industry, you are moving backward."

– Angelos Angelou, CEO AngelouEconomics, Austin, Texas

Case study highlights

The Austin case study highlights the importance of strategic local action in fostering science and technology capability within a region. Without such strategic planning and organization, it is unlikely that the region would have achieved its current levels of prosperity. Yet the case study also shows how important resources from upper levels of government are supporting this local effort. By coordinating local resources with those from the state and national government, the region has been able to leverage its infrastructure development to a globally competitive level.

The regional mobilization of strategic investment in Austin

In the ever-growing industry of regional performance indicators, the Austin-San Marcos region has stood out in more than a few rankings in the last few years. In 2002, it was ranked as having the strongest economy of any US city for the fourth year in a row[20] and placed second only to San Jose in the number of patents in 2000. In the following year, it was first in growth of patents[21] and was ranked third among US regions for the level of education of its work force; and in 2001, Austin was considered among the best places to live in the US by MSN.

Its standing on several fronts, especially on quality of life factors, can no doubt be partly attributed to the very pleasing surroundings. Yet much of what is being captured is the region's industrial prowess in high-technology, particularly in semiconductor research and manufacturing, software, computers and peripherals.

By the mid 1990s, there were some 275 technology manufacturers in the region, 60% of which were in the computer and electronics industry. Motorola, Advanced Micro Design, Samsung, Applied Materials, Tokyo Electron and Dell Computer are among the most prominent firms to have significant operations in Austin. By the late 1990s, they contributed to upwards of 68% of the total manufacturing in the region. In fact, it has been one of the few regions in North America that saw its manufacturing base expand consistently during the 1980s and 1990s. Its base is primarily high-technology related, with some of the larger firms such as Dell employing upwards of 20,000 people.[22] On the service side, the numbers are similar, with employment in software development, computer systems integration and software consulting accounting for approximately half of the 150,000 service employees by the mid-1990s.

It was, of course, not always thus. As the state capital and home to the University of Texas at Austin, the region's economy in the decades following World War II had been heavily represented by the government and education sectors, with agriculture still a major source of revenue in the area. Manufacturing is estimated to have been responsible for no more than 2% of employment in the mid-1950s.[23]

Yet following the goals laid out in a strategic planning report from 1957, local leaders committed themselves to developing an electronics industry in the region to diversify the economy. Though the transition itself spanned decades, the pivotal moment came in the early 1980s with the successful recruitment of the first major private sector research consortia in the US, the Microelectronics and Computer Technology Corporation (MCC). Five years later, the region's leaders made another successful recruitment, this time a major public-private research consortium called SEMATECH (SEMiconductor MAnufacturing TECHnology), which came with $1 billion US in federal support. Together, these two organizations crystallized the identity of Austin as a mecca for high-technology, building on a manufacturing base established by recruited companies such as IBM, Motorola and AMD.

Underpinning these successes was the University of Texas at Austin, whose expertise and commitment to microelectronics and industry outreach was a major draw for companies looking for knowledge and a skilled work force. In recruiting MCC, the university promised to triple the size of its microelectronics research program and establish 30 new endowed professorships in electrical engineering and computer science, at a cost of $50 million US.

In 2003, the state of Texas effectively endorsed this local system of strategic investment by establishing the Texas Technology Initiative (TTI). Funded through a new $295 million US Texas Enterprise Fund, TTI is part of a long-term economic development strategy to retain and recruit advanced technology industries, coordinate advanced technology activities throughout the state and accelerate commercialization. In the words of one Texas senator, the state now has an "economic development strike force, led by the governor, that will allow us to aggressively pursue the type of business opportunities that are going to re-ignite our Texas economy." One initiative funded thus far is a new $200 million US Texas Advanced Materials Research Centre, based in Austin. Its goal is to coordinate research between SEMATECH and the state's universities in order to establish leadership in new materials and capabilities — critical components of next-generation semiconductors, nanotechnology and biotechnology.

Raleigh-Durham

QUICK FACTS

POPULATION:	1,466,593
GRP:	N/A
GEOGRAPHIC SPAN:	RALEIGH DURHAM CARY CHAPEL HILL
USTPO PATENT APPLICATIONS:	2,494
SCIENTIFIC JOURNAL OUTPUT:	13,021
STAR SCIENTISTS:	56
MAJOR PUBLIC RESEARCH INSTITUTIONS:	4
VENTURE CAPITAL:	[# DEALS/TOTAL] 56 / $413 MILLION US
AVERAGE TECHNOLOGY WAGE:	$43,795 US

Case study highlights

As with Austin, Raleigh-Durham's research capacity has been enhanced considerably using a bottom-up strategy. Through effective coordination of the region's research institutions, Raleigh-Durham strengthened its research capacity in order to draw in both public and private investment and help shape its growth trajectory in the knowledge economy. The success of such strategic efforts has been dependent on national programs, such as federally funded research centres, that can be the focal point for local mobilization and coordination.

The regional mobilization of strategic investment in Raleigh-Durham

Raleigh-Durham's rise to technological prominence is one of the most unambiguous examples of how building a research capacity within a region can generate substantial economic benefits in technology sectors. In the early 1950s, at the initiative of the region's academics, a plan was developed in collaboration with state economic development officials that would coordinate the research strengths of the region's three main universities in the form of a research park. The goal was to attract new industries to the state and thus address the lack of well-paid jobs for the region's graduates. The park was called the 'Research Triangle', a name now synonymous with North Carolina's knowledge economy and which reflects the fact that it is triangulated by Duke University, North Carolina State University and the University of North Carolina at Chapel Hill.

The plan began to have an impact by 1965 with the decision by the federal government to locate a $70 million US National Environmental Health Science Centre in the park, followed soon after by an IBM research facility. By 2002, after year-on-year growth of about 35%, 106 research companies are now based in the park, along with a multitude of research centres.

Indeed, the three universities have been very successful at expanding the region's research capacity, not only by securing NSF-funded research centres — which help increase the amount of federal R&D dollars spent in the region — but also by enhancing local industry-university collaborations. North Carolina State, for example, has since the 1980s successfully competed for roughly a dozen federally funded research centres, including the Microelectronics Center of North Carolina and the Center for Advanced Computing and Communication.[24] This has in turn helped leverage industry-sponsored R&D, which is now the fifth-highest among land grant universities. Duke University is among the highest-ranked universities in terms of federally funded academic R&D, having reached $307 million US in 2003, a figure that is more than double 1996 levels.

NC State has recently taken a step further in supporting the local knowledge based economy by establishing another research park, Centennial Campus. To date, some $620 million US has been invested in park facilities and infrastructure, successfully luring some 70 companies and government agencies, include Swedish firm ABB, Lucent Technologies and Red Hat. It is expected that the campus will improve on this number threefold.[25]

These efforts have ultimately improved the overall health of the state economy. The Raleigh-Durham region now has a per capita income roughly equal to the national average, the effect of which has been to help lift the state's average income up from the third-lowest in the country in the mid-1950s.[26] Individual technology sectors have fared even better. Between 1990 and 1999, the region's average pharmaceutical / biotechnology wage reached $55,759 with an average annual growth rate of 6.8%, the eighth highest among the nation's 20 largest regions.[27]

The Raleigh-Durham region's strongest offering is in biotechnology, where it ranks as one of the nine most significant biotechnology centres in the US. With twice the research activity of the US biotech average, the region garnered $470 million US in National Institutes of Health funding in 2000. Similarly on the commercialization side, during the 1990s some $400 million US in venture capital was invested in the region, resulting in 46 new firms.[28]

Boston

QUICK FACTS

POPULATION:	3,015,981
GRP:	N/A
GEOGRAPHIC SPAN:	BOSTON CAMBRIDGE LOWELL WESTBOROUGH CONCORD
USTPO PATENT APPLICATIONS:	3,635
SCIENTIFIC JOURNAL OUTPUT:	29,363
STAR SCIENTISTS:	257
MAJOR PUBLIC RESEARCH INSTITUTIONS:	12
VENTURE CAPITAL:	[# DEALS/TOTAL] 375 / $2,368 MILLION US
AVERAGE TECHNOLOGY WAGE:	$46,432 US

Case study highlights

The mechanism by which Boston has built up and sustained its research and innovation capacity is inherent to the established and historically determined institutional strengths of the region. It has been highly effective in drawing down research funding — not so much from any regional economic development strategy, but rather from the military and technological aspirations of the country as a whole. These were effectively channelled into the Boston region's existing research organizations with the help of close contacts between the region's leaders and government decision makers.[29] Once established, the research might of the region continued to strengthen, making it one of the top industrial technology centres of the world and one which is able to adapt to emerging trends.

Embedded system of strategic investment in Boston

The Boston region is, by most measures, a quintessential knowledge economy. It is endowed with one of the most extensive educational and research systems in the world — some 65 universities and colleges across the Greater Boston Region — several of which are world renowned hubs of scientific and technological excellence, including the Massachusetts Institute of Technology, Harvard, Brandeis and Amherst. It has an extensive base of home-grown high technology firms, many of which were created by graduates and faculty of local universities. And it has the fourth-largest concentration of venture capital firms in the US, which supports one of the country's highest rates of commercialization from a region's research base. In biotechnology alone, the region accounts for more than 3,000 patents issued in the last decade and a fifth of the country's venture capital investments in the sector ($1.9 billion US).[30]

For a region that lost its industrial base in textiles and apparel in the 1930s and 1940s, these accomplishments are all the more remarkable, especially from an employment standpoint. Between 1968 and 1975 the region lost some 252,000 manufacturing jobs from traditional industries, only to replace them with another 225,000 manufacturing jobs in emerging sectors from 1975 through to 1980.

This transition to a high-technology research and industrial centre would not, however, have been possible without the vast influx of federal Department of Defence (DOD) R&D funds that poured into the region over several decades from World War II onwards. Disproportionately directed towards MIT and the region's firms, these funds steadily built up a military-related technological capability, providing seed capital to support many of the technological developments on which the region's electronics, analytical instruments and computer industries were based.[31]

In the final decade of the Cold War, from 1980 to 1989, New England received more defence spending per capita than any other region in the United States. Even today, DOD continues to be the dominant source of federal R&D in the State of Massachusetts, having invested almost $2 billion in 2001, representing a growth rate of almost 20% from five years prior. According to a recent study from the Massachusetts Technology Collaborative, the DOD is the primary source of funding for R&D carried out by industry, federal laboratories and federally funded research and development centres.[32]

Federal research funds are also a major driver in Boston's biotechnology industry. In 2000, the region received more research funding than any other region in the US — over $1.4 billion US in funding from National Institutes of Health, or 12.2% of the total.[33] In addition to this is the basic research funding from the National Science Foundation (NSF), a federal agency supporting basic research in science and engineering. Massachusetts is the fourth-largest recipient of NSF funds in the country, having received $358 million US in 2005.[34] Six new centre programs have been supported by the agency since 1996, including those established under the National Nanotechnology Initiative and the Information Technology Center program.

Although undeniably influential, public funding on its own does not explain the region's historical success. According to Castells and Hall, one of the explanations for the region's strength in commercialization stems from MIT's enthusiasm for contract research with government (i.e. DOD) and industry that dates back to the 1930s. With less money than its Ivy League neighbours, MIT made contractual cooperation a university policy, pioneering the trend towards university spin-offs.[35] As the authors note, "MIT's faculty and graduates used their advanced knowledge in new technologies, as well as their excellent personal contacts with the military establishment, to start companies [that would later] reproduce the spin-off process, giving birth to dozens of new companies..."

San Diego

QUICK FACTS	
POPULATION:	3,015,280
GRP:	$151 BILLION US
GEOGRAPHIC SPAN:	SAN DIEGO SAN MARCOS CARLSBAD WESTBOROUGH LA JOLLA
USTPO PATENT APPLICATIONS:	4,087
SCIENTIFIC JOURNAL OUTPUT:	11,929
STAR SCIENTISTS:	97
MAJOR PUBLIC RESEARCH INSTITUTIONS:	6
VENTURE CAPITAL:	[# DEALS/TOTAL] 154 / $1.253 BILLION US
AVERAGE TECHNOLOGY WAGE:	$45,669 US

Case study highlights

The San Diego region is widely recognized as one of the leading centres for research and innovation in the US, especially in the fields of biotechnology and the life sciences. However, none of this would likely have occurred without the strong initial presence of the US defense infrastructure in the region and a core group of defense contractors amply funded by the comprehensive research programs of the Department of Defense and other federal agencies. Equally critical was the ability of the region's scientists to draw upon the varied and diverse array of research funding made available by the federal government in the US. As in many other cases across the United States, the secret to the local community's high-technology success story is its ability to access and leverage the substantial sources of research funding provided by the federal government.[36]

Embedded system of strategic investment in San Diego

Over the past five decades, San Diego County has been transformed from a sleepy tourist destination and naval base into one of the most research–intensive regions in the US. In 1999, $1.26 billion US in non–classified federal R&D funding went into the region, of which $627.2 million came from the Department of Health and Human Services (including the National Institutes of Health) and $448 million from the Department of Defense.[37] In the state of California, this was second only to Los Angeles County. Despite this transformation, San Diego is still home to the largest concentration of military facilities in the world with more than $10 billion in military spending in 2001 representing eight per cent of the gross regional product.[38]

With respect to its status as a biotech and life sciences cluster, a recent report from the Milken Institute ranked San Diego first in the US, ahead of both Boston and San Francisco. In terms of scientific accomplishments, 10 University of California, San Diego (UCSD) faculty have been awarded Nobel Prizes, eight have been awarded the National Medal of Science in the US and USCD is ranked fifth in the world in terms of the most cited papers in molecular biology and genetic research, according to the Institute for Scientific Information.[39]

San Diego's research and high-technology areas are concentrated in two key clusters — wireless telecommunications and biotechnology/life sciences. The roots of their emergence lie in the growth of the US defense industry in the postwar era and key decisions by local business and civic leaders to attract key defense contractors and scientific research institutions to the region in the 1950s, followed by the campaign to create a local campus of the University of California system. Historically, the Department of Defense funded both the naval facilities and regional contractors in software, electronics and communications. A key development in the emergence of the telecommunications cluster was the decision by the city in 1956 to give a leading federal defense contractor called General Atomics — the divisional operations of General Dynamics responsible for nuclear research —120 hectares of land on the Torrey Pines Mesa on which to build a research centre. Subsequently, city officials designated the Mesa as a science and technology zone restricted to high-technology organizations.

The roots of the region's biotech and life sciences cluster date back to 1912 when the Scripps Institution of Oceanography became part of the University of California. However, the life science focus in the region was augmented in 1955 with the founding of the Scripps Research Institute (TRSI) as an offshoot of the Scripps Clinic Hospital. In the early 1960s, the city gifted 11 hectares of oceanfront property on the Mesa to Dr. Jonas Salk, discoverer of the polio vaccine, to establish the Salk Institute for Biological Studies. Subsequently, Salk brought to his institute some of the world's leading biological researchers, including Francis Crick, one of the discoverers of the double helix structure of DNA.[40] The missing piece of the region's research infrastructure was the presence of a world-class research university. This drew the attention of two of the region's leaders, Roger Revelle, Director of the Scripps Institute, and John Jay Hopkins, founder of General Atomics, who led the successful campaign to found the University of California, San Diego. The convergence of this core of private and public research institutions laid the basis for the gradual emergence and development of the region's dynamic industrial clusters in wireless telecommunications and biotechnology.

By the 1980s, the region of San Diego had clearly established itself as a leading centre for research and innovation in the US, but like many competitor regions, including Atlanta and Raleigh–Durham, it was shocked when it lost the national competition for the headquarters of the Microelectronics and Computer Technology Corporation (MCC), the US's first major for–profit R&D consortium, to Austin, Texas. The lesson of Austin's success was not lost on Richard Atkinson, the chancellor of UCSD, who moved to establish closer linkages between the university and the business community through the creation of organizations like UCSD CONNECT, designed to leverage the region's research base to achieve its innovation potential. UCSD CONNECT has grown into a major program in the region, promoting networking, advocacy, and assistance to high-technology firms. Other leading organizations linking individuals in the business, academic and government communities of the region include the San Diego Regional Economic Development Corporation, the San Diego Association of Governments and the San Diego Regional Technology Alliance.[41]

Bangalore – Emerging ICT Hotspot

Having captured a significant market share in the very IT service sectors once touted as the preserve of developed economies, Bangalore has become both a symbol of globalization and a source of much anxiety for the countries whose jobs are being outsourced. And by most estimates, this anxiety is well founded. It is estimated that 185 Fortune 500 firms have outsourced IT functions to Indian companies. In Canada, the phenomenon of outsourcing, which Bangalore has so eagerly benefited from, could potentially eliminate 75,000 Canadian IT jobs — or one in seven by 2010.[52]

Bangalore's strengths, however, go much beyond its willingness to be a subcontractor for the routine IT service functions of Western firms.[53] Indeed, it has become a dynamic ICT cluster in its own right, with an estimated 1,500 firms supported by 150,000 software engineers, in a state that graduates no less than 93,000 engineers a year. And the region is attracting a growing number of notable multinational firms, including Oracle (1987), Hewlett Packard (1989), IBM (1992), CISCO (1995), Intel (1998) and most recently, Google (2005), which has just opened up Google Labs India to support the company's global research efforts.[54]

Following partition in 1947, the Indian government made a decision to locate strategically sensitive industries away from potentially contentious borders.[55] Bangalore, safely located in southwestern Karnataka, thus became a 'city of choice' to concentrate key public institutions like the Indian Air Force and numerous science and engineering related universities, institutions and colleges, which are now responsible for producing much of the well-educated workforce that is attracting relatively high levels of inward investment.[56] Starting in the 1950s and 1960s, the Indian government invested heavily in Bangalore's electronics, aeronautics and telecommunications industries; the resulting knowledge base benefited from reduced tariffs and taxes, laxer foreign direct investment rules and later, the devaluation of the rupee in 1991. Texas Instruments was the first major multinational corporation to take advantage of this new climate, setting up a fully export-oriented, foreign owned and operated subsidiary in 1985, which now employs over 1,000 engineers and spent over $20 million US in R&D over the past 15 years.[57]

TORONTO REGION

PAST, PRESENT AND FUTURE COMPETITIVENESS IN RESEARCH AND INNOVATION

"We know that the countries and jurisdictions that invest in innovation, that tap the creativity of their people, that market their ideas most effectively, will be home to the most rewarding jobs, the strongest economies and the best quality of life."

– Ontario Premier Dalton McGuinty, Minister of Research and Innovation (October 7, 2005)

Toronto Region

QUICK FACTS

POPULATION:	6,919,000
GRP:	$255.6 BILLION US
GEOGRAPHIC SPAN:	TORONTO OSHAWA MARKHAM-MISSISSAUGA-BRAMPTON GUELPH-KITCHENER-WATERLOO BURLINGTON-HAMILTON
USTPO PATENT APPLICATIONS:	1,615
SCIENTIFIC JOURNAL OUTPUT:	16,265
STAR SCIENTISTS:	52
MAJOR PUBLIC RESEARCH INSTITUTIONS:	16
VENTURE CAPITAL:	[# DEALS/TOTAL] 101 / $328 MILLION US
AVERAGE TECHNOLOGY WAGE:	$32,670 US

The Toronto region is on the cusp of becoming one of the world's true megacentres of research and advanced technologies. Having successfully built upon existing strengths in key industry sectors and its extensive research base, the region is now home to several of North America's leading knowledge-intensive industry clusters. It has North America's second-largest automotive and financial services clusters, the third-largest information technology and telecom equipment cluster and the fourth-largest pharmaceutical and biotechnology cluster.[42] In employment terms, these sectors account for over 460,000 jobs and drive a significant share of the regional economy, which currently accounts for over 20% of the country's GDP and contributes annually some $3 billion Cdn in tax revenues to the rest of Ontario and $17 billion Cdn to the rest of Canada.[43]

Supporting this economic activity are numerous public institutions in the region, including eight universities, ten colleges, 60 hospitals and 37 medical institutions, which together give the region a strong foundation in knowledge generation, training and technology development. These capacities, however, have not developed by chance. Indeed, it has taken decades for this industrial know-how to accumulate within the region. Moreover, it has taken a sizeable commitment by the provincial and federal governments to invest in the region's universities, colleges and public research infrastructure that support research and development in the area's firms.

For example, the Ministry of National Defence's investments aimed at developing digital electronic computing capacity in Canada in the two decades following World War II, and later by the Department of Industry, Trade and Commerce, proved essential to establishing a globally competitive industrial capacity in microelectronics in Toronto.[44] In the span of two decades, the Canadian government had collaborated with several multinationals located in Toronto, including Ferranti, Westinghouse and Control Data Corporation, with the goal of procuring military technologies and developing the requisite expertise in Canada to support science-based defence technologies. Later, the federal government also established critical research infrastructure such as the Microelectronic Development Centre, the Micronet Centre of Excellence and the Canadian Microelectronics Corporation. All of these investments ultimately helped position Canada as one of only three countries, after the US and Taiwan, to have microelectronics design firms among the top thirty in the world.[45] Two of these, ATI Technologies and Genesis Microchip, have made important economic contributions to the Toronto region and the country as a whole.

This regional high-tech strength has been supported further by the region's prominent research universities. The University of Toronto alone spends an estimated $2 million Cdn a day on research activities.[46] In fact, the University of Toronto, having developed a globally recognized capability in microelectronics design, has drawn several prominent semiconductor firms to the Toronto region, including Xilinx, of

San Jose, Calif. (which established the Xilinx Toronto Development Centre), and Altera, which set up the Altera Toronto Technology Centre after acquiring a firm from a University of Toronto professor. Many successful spin-off companies from the region's research institutions exist; among the best known are Research in Motion and Open Text.

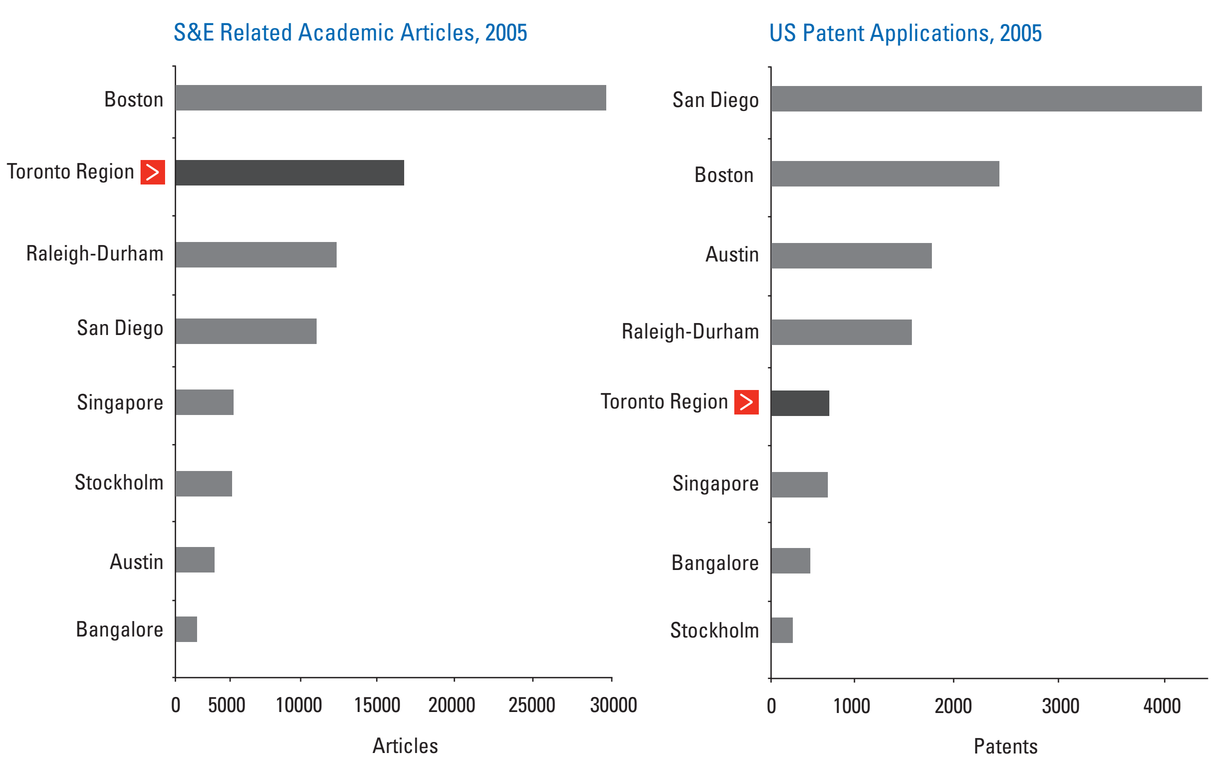
Present challenge

Yet for all its current research and industrial strengths, it is by no means certain that the Toronto region can continue to prosper. The remarkable growth in global competition in advanced technology industries, together with the major investments being made by governments around the world to strategically support research and innovation, present a major challenge to the Toronto region.

The region is also faced with a longstanding weakness in commercialization, which can be a significant barrier to its ability to capitalize on its research capacity. As the recent Report of its Expert Panel on Commercialization noted, this problem is not endemic to just Toronto, but to Canada as a whole, where firms have traditionally competed on cost as opposed to excellence and innovation.[47]

Though commercialization is not readily measured by any one indicator, Figures 5 and 6 give some indication of this weakness in the Toronto region. The region's research institutions collectively compare very well in terms of knowledge generation, ranking second only to Boston in science and engineering articles published in 2005. Yet when it comes to transforming such knowledge into new products and services, the region fares less well, placing fifth in US patent applications among competing regions. This modest performance is also reflected in venture capital investments, which shows Toronto receiving the least amount compared to competing US regions.

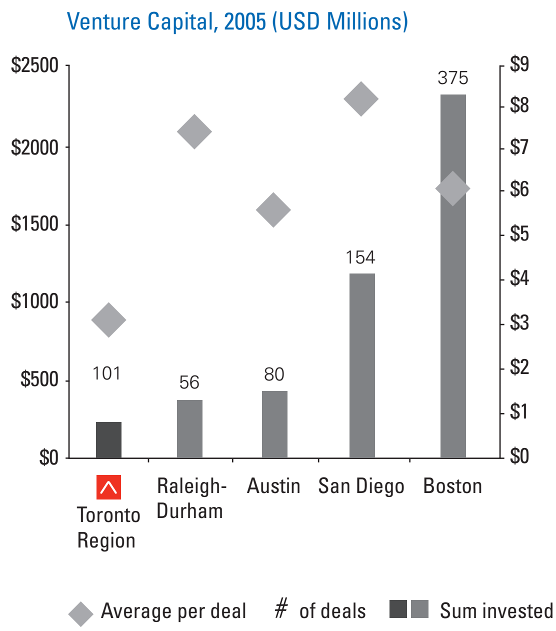
Figure 5: Commercialization gap



Source: ISI Science Citation Index, 2006

Source: USTPO, 2006

Figure 6: VC investments in the Toronto region



Source: Thompson Financial, 2006

Paradoxically, the Toronto region is further challenged by its status as Canada's largest economic centre. Having the strongest regional economy in the country, governments have typically left the region to its own devices. Indeed, it sits within the only region in Canada without a federal strategy for regional development, a status it has held since 1957, when the country first established regional economic policies focused on regional growth.[48] Moreover, it's the only major centre without a National Research Council institute, one of the cornerstones of Canada's R&D system.

The region has thus relied on its public research institutions for its research capacity and investment in a similar manner to Boston. With 16 major public research institutions, the Toronto region effectively has an embedded advantage similar to Boston when drawing down national research funds from the country's R&D system and in attracting firms.49 The region's research institutions, for example, received $660 million from the Canadian Foundation for Innovation over six years to strengthen its infrastructure. In health sciences, some $1.204 billion was disbursed in grants from the Canadian Institutes of Health Research (CIHR) to the region since 1999.

These amounts are modest, however, when compared to the investments made in competing regions to support globally competitive research intensive industries. In 2000, for example, Boston received $1.4 billion US from just one US agency, the National Institutes of Health. And even within Canada, the funding that the Toronto region receives is, on a per capita basis, lower than for any other major city-region.[50] In 2004/05, the region's institutions received 21.1% of total funds allocated, despite the fact that it performs 35% of all R&D in the country and accounts for 33% of Canada's most highly-cited scientists.[51]

Thus while the region undoubtedly has an embedded comparative advantage in drawing in public investments within Canada, it is by no means certain whether, in a global context, this is enough to sustain its R&D competitiveness. Countries are spending ever more of their GDP on R&D, and are doing so strategically in a way that is having a real impact on the geography of global innovation.

Moreover, with no federal regional development agency supporting the region's advanced technology industries with strategic investments, the Toronto region has not benefited from any major technology-focused economic development investments of the kind being made by Singapore, for example. These two aspects together may offer some part of the explanation of why the Toronto region, despite a first-rate research capacity, has not been as successful at commercialization as have many of the other regions.

THE WAY FORWARD: LESSONS FOR THE TORONTO REGION

For the Toronto region to fully develop into a world-class centre of research and innovation, it will need to strongly commit itself to addressing the key challenges facing the region's research and innovation capacity. In examining several of the leading research centres in the world, this study offers several lessons that can assist the region in this task.

The first concerns the role of national governments in supporting regional research strengths. The cases classified as *dirigiste* forcefully highlight how national governments can play a very significant and strategic role in the knowledge economy and have a tangible impact on research and innovation capacity.

Singapore's talent recruitment efforts and Sweden's public venture capital fund are compelling examples of such roles. Indeed, early on in Toronto's development of its technology capabilities, the federal government used similar efforts to build a capacity in electronics and computing. The impacts of these efforts are still visible today in the Toronto region. The importance of federal investments to building science- and technology-based capabilities, however, is most striking in Boston and San Diego. These regions have both been major recipients of defence spending, which helped establish early on much of the capabilities that now drive the respective regions' significant competitive advantage in science- and technology-based economic development.

Yet in an era of limited Canadian defence R&D spending and when few strategic efforts are being made by the government, the lessons from the regions that have acted locally to secure the necessary resources to establish their competitiveness are particularly relevant. Austin and Raleigh-Durham have each successfully mobilized and coordinated local resources — such as universities, firms, money and talent — to draw in funds from upper levels of government, attract firms and develop a globally competitive research and innovation capacity.

Austin, in particular, highlights the importance of strategic local coordination and planning to ensure that the right people and resources are brought together to identify existing strengths and plot a course of needed investment that develops and sustains these strengths. The case of Raleigh-Durham reveals how strategically mobilizing the region's research institutes can help regions successfully compete for more research funding. This enhanced capacity subsequently became a major draw for high-tech companies seeking to benefit from the proximity to the knowledge base. And finally, San Diego points to how an existing research capacity can be successfully leveraged by far-sighted civic leaders and entrepreneurs, who emerged from their laboratories to found anchor companies.

For this approach to work, therefore, governments must provide the flexibility in their support for R&D such that regions across the country can draw down R&D funding according to their own investment needs.

Given that the Toronto region is similarly situated within a multilevel federal system with devolved responsibilities for economic development, such lessons are all the more relevant. Indeed, there is opportunity now in the Toronto region for this *regional mobilization* model to work. With an intimate understanding of its own research strengths and innovation potential in key advanced technology industries, the region is well positioned to take responsibility for its science- and technology-based economic development, provided it can effectively coordinate its resources to make the needed investments. However, without resources made available by the national and provincial governments to support the outcomes of local strategies, the *regional mobilization* model will have its limits.

For this approach to work, therefore, governments must provide the flexibility in their support for R&D such that regions across the country can draw down R&D funding according to their own investment needs. Be it for a new research institute, specialized training programs or to attract a major R&D firm that complements local industry strengths, such tailoring of investments to local needs will prove crucial to sustaining a foothold in rapidly changing global technology markets.

This approach would likely benefit not just the Toronto region but also all of Canada's centres of research and innovation, including those less developed urban regions. Exposed to the dynamics of a global knowledge economy, leading regions require the flexibility to adapt their local economies and knowledge infrastructure to the ever-changing technology markets. The *regional mobilization* model of strategic investment can facilitate this process. As for the less developed regions, it can offer important flexibility and resources to chart their own course of economic development, according to their own aspirations and local strengths.

APPENDIX A: FACTS ON NATIONAL R&D SYSTEMS

United States

The US is the single largest performer and supporter of R&D in the world, devoting 2.7% of its GDP, or some $318 billion US, to R&D. This amount accounts for approximately 43% of total R&D in OECD countries. The federal government is responsible for a third of this amount, with expenditures expected to reach $137 billion for 2007, up 50% since 2001.[63]

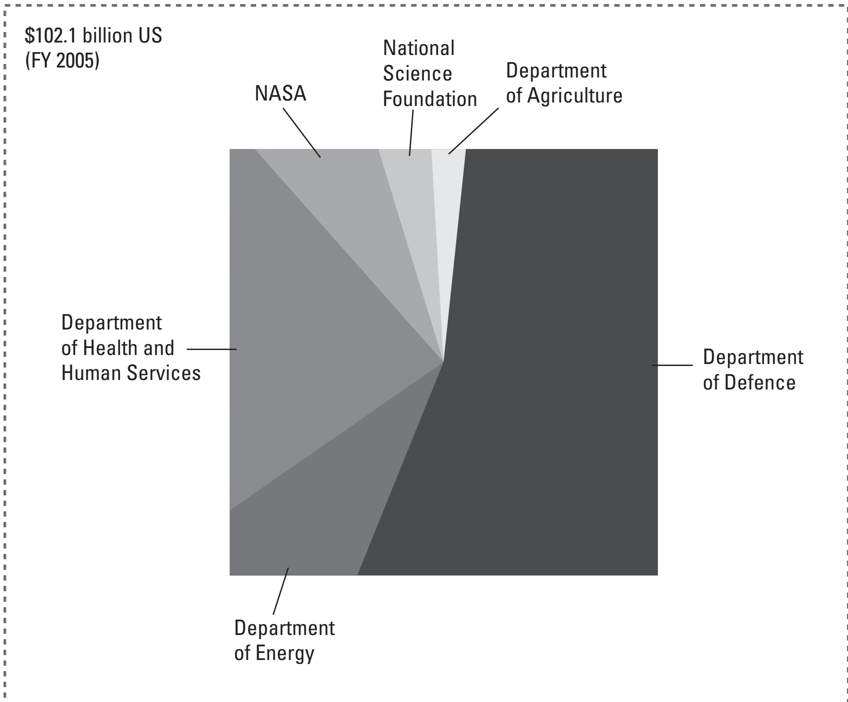
Six government bodies are responsible for administering over 95% of government R&D funding. The largest is the Department of Defence which accounts for just less than half of the total, followed by the Department of Health and Human Services (including the National Institutes of Health) at 27% and NASA at 8%.

There are an estimated 16,000 R&D labs in the country, including 12,000 in private industry.[64]

The United States publishes considerably more scientific and engineering articles than any other country, accounting for 38% of all such articles between 1997 and 2001.[65]

Figure 7: Major US Federal R&D Initiatives

Top US Federal Funders of R&D, 2005



Source: Science and Engineering Indicators, 2006

Initiative	Overall budget US$	Goals
American Competitiveness Initiative	$136 billion over 10 years 2007 allocation: $5.9 billion	Double the government's commitment to critical basic research programs in the physical sciences over the 10 years Improve environment for additional private-sector investment in innovation Improve the quality of education especially in math and science Support universities that provide world-class education and research opportunities Provide job training for workers and manufacturers to improve their skills and better compete in the 21st century Attract and retain the best and brightest Foster a business environment that encourages entrepreneurship and protects intellectual property
National Nanotechnology Initiative	$6.7 billion since 2001 2007 allocation: $1.277 billion	Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology Support responsible development of nanotechnology
Networking and Information Technology	$13.7 billion over 6 years 2007 allocation: $2.783 billion	High-end computing (HEC) Deploy petascale computing systems by the year 2010
Advanced Energy Initiative	$10 billion since 2001 through DOE clean-energy technology research 2007 allocation: $2.146 billion	Develop cleaner, cheaper and more reliable alternative energy sources Break US dependence on foreign sources of energy
Hydrogen Fuel Initiative	$1.2 billion over five years 2007 allocation: $ 289 million	Scientifically support industry efforts to develop practical and cost-effective technologies for producing, distributing, and using hydrogen to power automobiles

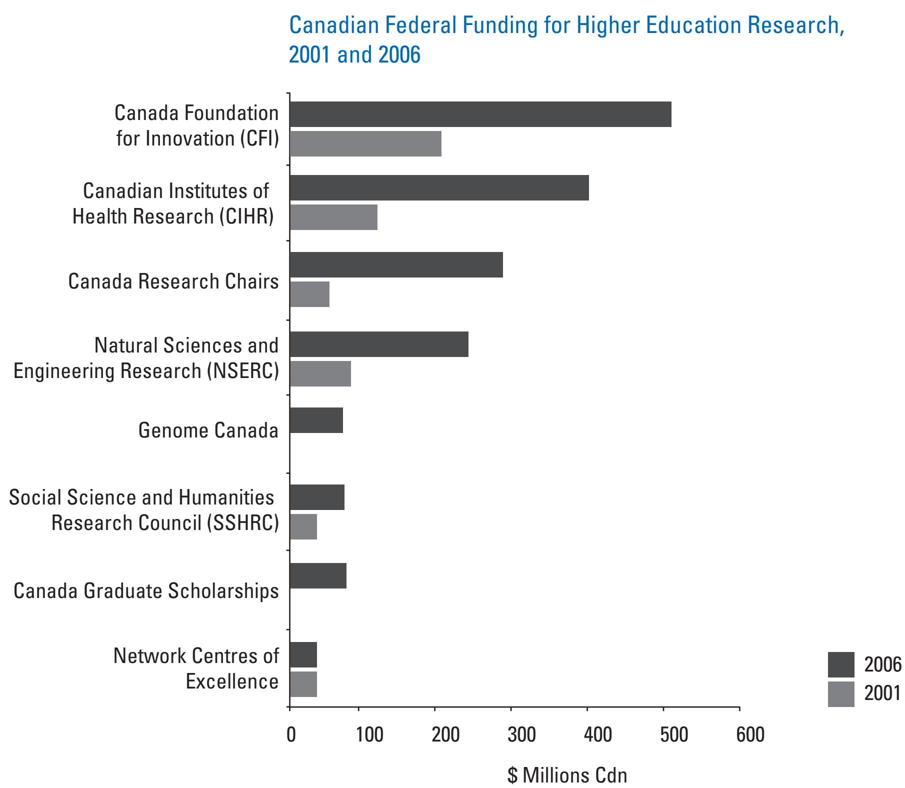
Canada

With gross expenditures on R&D registering at almost 2% of GDP, Canada is a relatively modest R&D contributor, ranking 13th among OECD member states in 2003. This comes despite the fact that the government has increased its own spending on S&T activities by nearly 40% in real terms over the past decade.[66] Total expenditures amounted to $5.48 billion Cdn in 2003-04, with the federal government funding 19%, business 46% and higher education 18%.

The top three federal agencies with the largest expenditures on research in the education sector are: the Canada Foundation for Innovation, which invests in research infrastructure and equipment; the Canadian Institutes of Health Research, which is the key financer of health science research; and the Canada Research Chairs program, which aims to attract and retain some of the world's top researchers. Among government performers of R&D, the National Research Council is the largest actor followed by Agriculture and Agri-foods Canada and Natural Resources Canada.

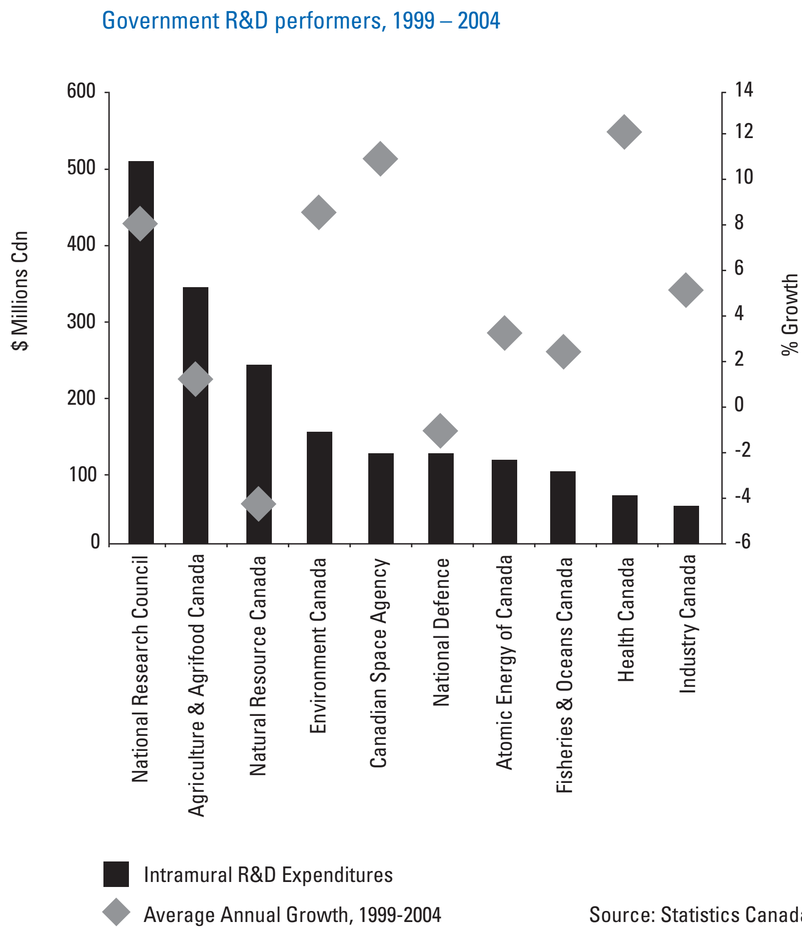
As with Sweden, much of the business sector R&D is carried out by disproportionately few firms – the top 10 companies have carried out one-third of all intramural R&D on average over the past two decades.[67]

Figure 8: Higher Education Research Funding



Source: Industry Canada, 2005

Figure 9: Government R&D performers



Source: Statistics Canada, 88-204-XIE

The government supports business R&D primarily through the tax system as opposed to through subsidies in the form of direct spending, as do most other OECD countries. According to recent statistics from the OECD, for example, direct spending towards business R&D amounted to less than 3% of total business R&D expenditures, compared to approximately 6% in Sweden and 11% in the US. Canada business R&D is subsidized by approximately 25% through R&D tax credits, compared to about 6% in the US and less than zero in Sweden.

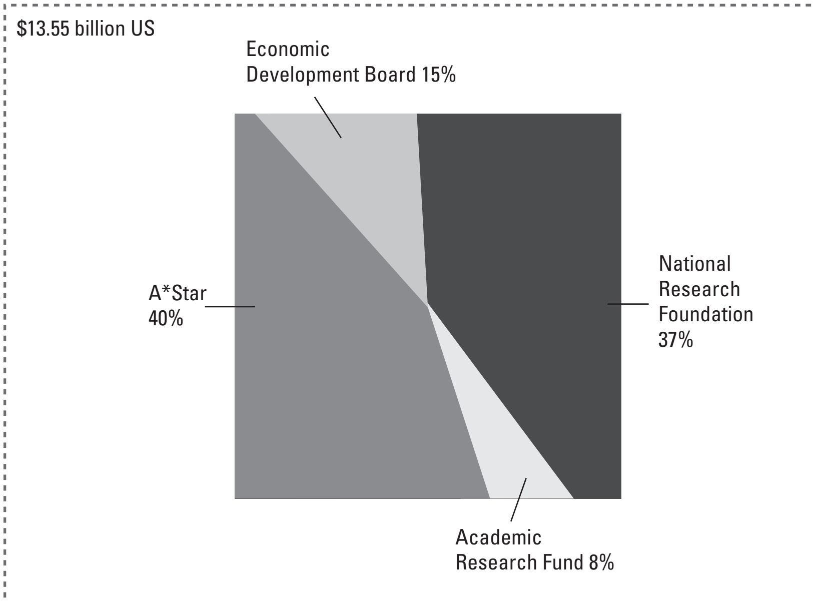
Singapore

Singapore has, through three successive five-year strategic plans, developed a very strong R&D system and research capacity. From its first plan in 1991, to the current S&T Plan 2005, which comes to an end in the current year, gross expenditure on R&D as a percentage of GDP increased from 0.85% to 2.25% in 2004, after having spent $12 billion US. This remarkable growth change is matched by the dramatic 210% increase in the number of research scientists and engineers in Singapore in the same period — from 28 in 1990 to 87 per 10,000 members of the labour force in 2004.

Under the new S&T Plan 2010, which has a five year budget of $13.55 billion US, the national government expects to increase R&D expenditures to 3% of GDP. As in previous plans, the government will be highly strategic in developing its science and technology based industries, allocating resources to those areas where there is the most potential for scientific breakthroughs to yield economic benefit for Singapore.

Figure 10: Singapore's new S&T Plan 2010

Top Singapore funders of R&D, 2006 – 2010 Plan



Source: Ministry of Trade and Industry Singapore, 2006

Singapore's national R&D system is directed by two organizations: the Ministry of Trade and Industry, which pursues mission-oriented research through A*STAR (Singapore's Science and Technology Agency) and the Economic Development Board; and the Ministry of Education, which supports academic and investigator-led research through the Academic Research Fund. As of 2006, a new body called the National Research Foundation will fund longer-term strategic programs in the areas of national research, innovation and enterprise.

Initiative	Overall budget US$	Goals
Science and Technology (S&T) Plan 2005	$6 billion budget since 2001	Strengthen R&D capabilities in niche areas, nurture local talent and recruit global talent and work with industry through technology transfer and other mechanisms $4 billion to A*STAR to boost local R&D capabilities: to set up key Research Institutes (RIs) and recruit international talent to head up these institutes and labs A*STAR RIs produced some 6,790 scientific publications in Science Citation Index and Engineering index journals and filed 739 patents $2 billion US to Economic Development Board to promote private sector R&D in Singapore
Science and Technology (S&T) Plan 2010	$13.55 billion	Achieve R&D of 3% of GDP by 2010 Double the jobs in life sciences, environmental and water technologies and digital media sectors to 80,000 and triple the value-added to $27 billion by 2015

Sweden

Sweden is one of Europe's innovative leaders, ranking first among the European Union (EU) countries along with Finland. In the 2005 European Innovation Survey (EIS), the country displayed above-average performance on all indicators, with exceptionally strong business R&D expenditures, early stage venture capital and patenting.

Sweden's investments in education are among the largest in the world relative to the size of the economy. In 2001, total spending on R&D amounted to 4.3% of gross domestic product (GDP), which is the highest level in the OECD. And according to EIS, Sweden continues to pull ahead of the EU trend for public R&D.

The business sector accounts for 78% of total R&D spending, second only to the US. As for research financed by the central government, R&D appropriations for the 2003 budget year were kr 23.7 billion SEK ($3.05 billion US).[68]

The country's R&D system is dominated by performing sectors, industry and the universities. The extensive industry R&D is largely accounted for by the activities of ten multinational industrial groups, led by Ericsson and AstraZeneca. Sweden's largest and oldest universities are responsible for most of the R&D in the university sector, overseeing various public and private R&D institutions. These universities collectively produce a very high research capacity. The country is one of the largest producers of scientific knowledge in the world measured in terms of scientific publications per capita. Only Switzerland produced more scientific knowledge per capita than Sweden both in 1986-1990 and in 1991-1995.[69]

Initiative	Overall budget US$	Goals
Vinnväxt: Regional growth through dynamic innovation systems	~ $40.74 million over 10 years	Stimulate strong systems with qualified environments for research and development, as well as regional competitive and dynamic networks, in order to achieve more innovations and lasting growth innovation VINNVÄXT is built around a concept where a few selected regions receive financing over 10 years and are regularly evaluated in order to secure progress
The ProViking programme	~ $20.50 million over 5 years	Support product realization research — product development, manufacturing, product support and maintenance in a life-cycle perspective. The main focus is on industry with manufacturing and/or development, operating in Sweden
Institute Excellence Centres	~ $32.3 million over 10 years	Create knowledge within areas of strategic importance to strengthen the competitiveness of Swedish industry
Industrial Development Centres	N/A. ~ $41 million between 1997 and 2002	Exist as the "missing link" that enables co-operation between enterprises and other important actors by providing access to all the resources necessary to run strategic development work
Key Actors Programme	~ $27.2 million over 12 years	Develop competence, methods, processes and structures to enhance the professionalism of key actors in the Swedish innovation system Increase the amount and efficiency of co-operation between research performers, industry and other actors Activate knowledge (i.e. knowledge transfer and commercialization of research results)

APPENDIX B: NOTES ON QUICK FACTS SOURCES

USTPO Patent applications (2005)	Total patents as determined by inventor city of residence, aggregated for the region of interest.
Scientific journal output (2005)	Data is aggregated by institute. Source is ISI Thompson Scientific.
Star scientists (2005)	The number of highly cited scientists as measured by ISI Thompson Scientific.
Major public research institutions (2005)	Includes those institutions with significant publishing records. Data is calculated from scientific journal output, ISI Thompson Scientific.
Venture capital (2005) [# deals/total]	VCReporter & Venture Expert Solutions, Thomson Financial LLC.
Average technology wage (2002)	Average estimated from NAICS 31-33, 51, 54 and 62. US Census Bureau and Statistics Canada.

NOTES

[1] See N. Low and M. Gertler.2005. 'Diversity and the Evolution of a Life-Science Innovation System: The Toronto Region in Comparative Perspective'. In D. Wolfe and M. Lucas, Global Networks and Local Linkages. Montreal: McGill-Queen's University Press, and J. Matuszewski and F. Chevalier (2004) 'Greater Toronto Area ICT Study' E&B Data, for discussion of life sciences and ICT in the Toronto region respectively.

[2] 'Technology intensive industries now account for a full two-thirds of total manufacturing exports among OECD countries, and in Canada, these industries now account for close to half. J. Khondaker, 2005. 'Trends in the technology intensity of Canadian exports: A comparison with other countries (III-G)', Statistics Canada. For international statistics see OECD, STI Outlook 2003. Paris: OECD.

[3] Estimate from National Science Foundation. Cited from SEMATECH News, April 18, 2006. 'Austin Community College and SEMATECH Partner with the State of Texas to Launch Nanoelectronics Training Program'.

[4] Most of the regions extend beyond any one city, reflecting the fact that there are often strong functional linkages and interdependencies among firms, institutions and infrastructure. Stockholm, for example, includes Uppsala and the surrounding region, Raleigh-Durham includes Cary and Chapel Hill, and Toronto includes the Greater Toronto Area, Kitchener-Waterloo, Hamilton and Burlington.

[5] Financial Times, July 22/23, 2006. "The great leveler in a rising land".

[6] A. Wolff, T. Howell, Bartlett and R Gadbaw (eds.), Conflict among Nations: Trade Policies in the 1990s, San Francisco: Westview Press, 1992, p. 528.

[7] Battelle Technology Partnership Practice and SSTI, Laboratories of Innovation, June 2004.

[8] According to the study, the top 10 of 51 biotech centers received over 60% of NIH funding (2000), 89% of the industries venture capital (1995 -2001), and 82% of IPOs (1998-2001). J. Cortright and H. Mayer, 2002. Signs of Life: The Growth of Biotechnology Centres in the US, Centre on Urban and Metropolitan Policy, Brookings Institute.

[9] This low ranking is partly offset by the fact that Canada offers generous R&D support through the tax system as opposed to through subsidies in the form of direct spending as do most other OECD. According to recent statistics from the OECD, for example, direct spending towards business R&D amounted to less than 3% of total business R&D expenditures, compared to approximately 6% in Sweden and 11% in the US. Canadian business R&D is subsidized by approximately 25% through R&D tax credits, compared to about 6% in the US. Sweden offers no such tax based subsidies to its firms.

[10] Research on Canada's R&D intensity finds three broad factors influencing relatively low levels of R&D: industry composition, and in particular the dependence of Canada on the resources and automotive sector, the latter of which is less R&D-intensive; the degree of foreign ownership (foreign subsidiaries typically do not carry out R&D outside their home markets); and third, the smaller size of Canadian firms. Smaller firms typically spend less on R&D than larger firms. Much of Sweden's industrial R&D, for example, is driven by a handful of very large pharmaceutical firms. See Aled ab Iorwerth, 'Canada's Low Business R&D Intensity: the Role of Industry Composition', Working Paper 2005-03, Department of Finance, Canada.

[11] This amount includes allocated funding for CRC. Source: CFI Awards database, CRC and Genome Canada respectively.

[12] See P. K. Wong, 2002. 'ICT Production and Diffusion in Asia: Digital Dividends or Digital Divide?', Information Economics and Policy, 14 (2): 167-187; and Wong, P.K.(2001), 'Leveraging Multinational Corporations, Fostering Technopreneurship: The Changing Role of S&T Policy in Singapore', International Journal of Technology Management, Vol.22, No. 5/6: 539- 567.

[13] D. Finegold, P.K. Wong and T. Cheah. 2004. 'Adapting a Foreign Direct Investment Strategy to the Knowledge Economy: The Case of Singapore's Emerging Biotechnology Centre'. European Planning Studies, Vol. 12, No. 7, October 2004.

[14] Finegold, et al. 2004.

[15] The normal rate is 25.5%. T. Howell. 2003. 'Competing programs: Government support for microelectronics'. In C. Wessner (ed.) Securing the Future: Regional and National Programs to Support the Semiconductor Industry, National Research Council, Washington D.C., p. 213.

[16] See T. Howell, 'Competing Programs', p. 217.

[17] S. Steinmo. 2002. 'Taxation and Globalization: Challenges to the Swedish Welfare State', Comparative Political Studies, Vol. 35, no. 7, pp. 839-862.

[18] Despite all-time-high profits, the large industrial groups with activities in Sweden have been reluctant to reinvest in Sweden, which has led to a decline in technology employment. See European Commission: Sweden 2004-2005, Annual Innovation Policy Trends and Appraisal Report, European Trend Chart on Innovation.

[19] European Commission: Sweden 2004-2005, Annual Innovation Policy Trends and Appraisal Report, European Trend Chart on Innovation.

[20] POLICOM Corporation, www.policom.com.

[21] Ranking from the Centre on Urban and Metropolitan Policy, Brookings Institute.

[22] Angelou Economic Advisors Inc. An Economic Review and Forecast 1996-1998, Austin, Texas.

[23] An estimate by the Austin Chamber of Commerce cited from P. Robbins. 2003. 'The Town that Won the Pennant: A Short History of Austin's Economic Development'. The Austin Environmental Directory.

[24] These include Centre for Advanced Computing and Communications, the Center for Advanced Processing and Packaging Studies, the Center for Integrated Pest Management, Nonwoven Cooperative Research Center, the Silicon Wafer Engineering and Defect Science Center and the Lymphocite Technology Centre.

[25] L. Tornatzky, P. Waugaman, and D. Gray. 2002. Innovation U: New University Roles in a Knowledge Economy. Southern Growth Policies Board.

[26] US Bureau of Economic Analysis.

[27] M. Porter. 2001. Research Triangle, Clusters of Innovation Initiative, Council on Competitiveness, Washington, D.C.

[28] J. Cortright and H. Mayer. 2002. Signs of Life: The Growth of Biotechnology Centres in the US, Centre on Urban and Metropolitan Policy, Brookings Institute.

[29] See M. Castells and P. Hall. 1994. Technopoles of the World: The Making of 21st Century Industrial Complexes. London: Routledge. p. 36, for a discussion on the links between top academics and government officials.

[30] J. Cortright and H. Mayer. 2002.

[31] R. Kispert. 2004. 'The R&D Funding Scorecard: Federal Investments and the Massachusetts Innovation Economy', Massachusetts Technology Collaborative.

[32] R. G. Kispert. 2004. 'The R&D Funding Scorecard: Federal Investments and the Massachusetts Innovation Economy', Massachusetts Technology Collaborative, Innovation Outlook Series.

[33] Cortright and Mayer, Table 7.

[34] NSF, 2006. Budget Internet Information System.

[35] M. Castells and P. Hall. 1994.

[36] M. Pugh O'Mara. 2005. Cities of Knowledge: Cold War science and the search for the next Silicon Valley, Princeton University Press, Princeton, NJ.

[37] M. Walshok, E. Furtek, C. Lee and P. Windham. 2002. 'Building regional innovation capacity: The San Diego Experience', Industry and Higher Education: 27-42.

[38] San Diego Regional Economic Development Corporation, 'Region needs "grassroots publicity plan"', Newsletter, June 21, 2006.

[39] R. DeVol, P. Wong, K. Junghoon, A. Bedroussian and R. Koepp. 2004. America's Biotech and Life Science Clusters: San Diego's Position and Economic Contributions, Milken Institute, Santa Monica, CA.

[40] DeVol et al. 2004.

[41] M. Porter. 2001. Council on Competitiveness, Monitor Group, and On the Frontier, San Diego: Clusters of Innovation Initiative, Council on Competitiveness, Washington, D.C.

[42] Toronto Region Research Alliance, 'Engaging Innovation', October 2005.

[43] Employment figure from Industry Profiles, Greater Toronto Marketing Alliance. Tax data is from Toronto Region Research Alliance, 'Engaging Innovation'.

[44] Some of the most important investments were initially made by the Department of Defence and later the Department of Industry, Trade and Commerce (DITC). See T. Creutzberg 2005. 'Scalar dimensions of non-market governance in knowledge economies: A look at the microelectronics industry in the Greater Toronto Region', Paper from the 2005 CPSA Annual Conference. http://www.cpsa-acsp.ca/papers-2005/Creutzberg.pdf.

[45] IC Insights, 2004. 'Leading Fabless IC Suppliers -2003'. http://www.icinsights.com/news /releases/press 20031201.html.

[46] N. Lowe and M. Gertler. 2005. 'Diversity and the Evolution of a Life-Science Innovation System: The Toronto Region in Comparative Perspective'. In D. Wolfe and M. Lucas, Global Networks and Local Linkages. Montreal: McGill-Queen's University Press.

[47] Canada. 'People and Excellence: The Heart of Successful Commercialization', Volume I: Final Report of the Expert Panel on Commercialization, 2006. p. 7.

[48] See OECD 2002. Territorial Reviews: Canada, Paris: OECD, Chapter 2.

[49] Toronto's major public institutions include those with significant scientific publications, and which are recognized by ISI Thompson Scientific.

[50] According to a study by the Boston Consulting Group, the Toronto Region received $69 in per capita funding from the granting councils compared to $95 per capita in Vancouver, $85 per capita in Ottawa, $77 per capita in Montreal, and $73 per capita in Calgary. Boston Consulting Group. 2005. The Role of the Federal Government in the Development of the Public Research Base in the Toronto Region.

[51] Boston Consulting Group. 2005.

[52] PriceWaterhouse Coopers. 2004. A Fine Balance: The Impact of Offshore IT Services on Canada's IT Landscape.

[53] Rosenberg D. 2000. Cloning Silicon Valley: the next generation of high-tech hotspots. London: Pearson Education, p. 129.

[54] The New Scientist. 'India Special: The Silicon Subcontinent', 15 February 2005.

[55] Bangalore's industrial capabilities actually began to develop before independence when the British in 1940 created Hindustan Aeronautics Limited (HAL) in support of the war effort. See R. Basant. 2006. 'Bangalore Cluster: Evolution Growth and Challenges', Working Paper 2006-05-03. Indian Institute of Management, Ahmedabad, p. 5.

[56] A recent empirical study on India's software sector found that the availability of skilled graduates is one of the strongest factors that accounts for the growth of software exports. See A. Arora and S. Bagde 'The Indian Software Industry: the Human Capital Story', DRUID Conference Paper, May 23, 2006.

[57] Basant. 2006, p. 27.

[58] T. Howell. 2003. 'Competing programs: Government support for microelectronics'. In C Wessner (ed.) Securing the Future: Regional and National Programs to Support the Semiconductor Industry, National Research Council.

[59] E. Schumann. 1997. 'China on Fast Track For Building IC Capacity', Vol. 10, No. 2, SEMI.

[60] Y. Zhongyu. 2005. China Semiconductor Industry Association, November, 2005. http://iisdb.stanford.edu/evnts/4307/Yu_Zhongyu_CSIA_slides.pdf.

[61] Albany Nanotech is the name given to describe a coordinated program undertaken by the State of New York to establish the Albany metropolitan area as a global center for the development and production of the next generations of semiconductor devices. Commercial semiconductor devices are beginning to offer sub-100 nanometre feature sizes, and it is generally thought that the semiconductor industry will need to utilize nano-engineering to develop new methods of production that will yield even higher levels of performance.

[62] M. Johnson, 'Advanced Micro Devices Is Considering Building a $3.5 Billion Chip Plant in Upstate New York' Canadian Business Online. June 20, 2006.

[63] Office of Science And Technology Policy. 2006. FY 2007 Federal Research and Development Budget Presentation, Executive Office of the President, Washington D.C.

[64] M. Crow and B. Bozeman. 1998. Limited by Design R & D Laboratories in the U.S. National Innovation System. New York: Columbia University Press.

[65] K. Hill. 2006. 'Universities in the U.S. National Innovation System', Arizona State University's Productivity and Prosperity Project.

[66] OECD. 2006. Economic Survey Canada. Paris: OECD.

[67] Statistics Canada. 2005. Federal Scientific Activities, 2004 – 2005. Statistics Canada, Ottawa.

[68] VINNOVA, The Swedish National Innovation System: 1970–2003.

[69] VINNOVA. The Swedish National Innovation System: 1970–2003.

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