Technological Progress and Competitiveness in the Canadian Forest Products Industry

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Preface

In 1997, the Canadian Council of Forest Ministers (CCFM) released a technical report that provided a series of measures (or indicators) to assess the status of sustainable forest management in Canada from currently available information. The report underlined the importance of industrial competitiveness:

> Measures of competitiveness are an important element of sustainability for two basic reasons. First, the ability of forest industries to continue to provide jobs and incomes and pay corporate taxes to governments is dependent on their ability to continue to access foreign markets, earn profits, and attract new investment. Second, the relative efficiency and competitiveness of firms determines their ability to absorb the higher costs that may be associated with more environmentally sensitive resource development and industrial production (CCFM 1997, p. 88, 89).

One of the indicators reported in the CCFM technical report is trends in research and development (R&D) expenditures in forest products and processing technologies. The report finds that R&D expenditures have not kept pace with the value of sales and that this may cause a decline in future competitiveness. This conclusion leads to but does not answer a wide range of questions and issues concerning the technological capacity of the forest industry, the process of technological innovation, and the industry's future technological capacity requirements.

This present study complements and extends the analysis provided in the CCFM technical report. Its analyzes the relationships between R&D, technological progress, and competitiveness. The study has a number of more specific goals including to describe the process of technological innovation and the factors that influence the rate of innovation in the Canadian forest industry, to provide an assessment of the technological capacity of the forest industry, to develop a better understanding of structural changes in the global marketplace and the implications of these changes for the technological requirements of the forest industry, and to discuss institutional design and the possible roles of government, industry, and research alliances in technological innovation.

We hope that the information and analysis provided in this report will lead to a more informed discussion of issues related to technological innovation and possible strategies for addressing them. Moreover, we trust that the report will be a basis for interpreting the information on forest sector competitiveness being developed through the CCFM's Criteria and Indicator Framework.

Acknowledgments

Interviews with Canadian forest products sector R&D experts (identified in Appendix 1) were an important source of information for this study. We sincerely thank these experts for sharing their knowledge, experience, and expertise with us. The information provided was invaluable. We also thank members of the technical review committee for their many helpful comments, suggestions, and directions: Bob Jones, Natural Resources Canada(NRCan), Canadian Forest Service (CFS), Ottawa; Subhash Junéja, Industry Canada, Ottawa; Hans Ottens, NRCan, CFS, Ottawa; and Bill Wilson (Chair), NRCan, CFS, Victoria. We thank Catherine Carmody, NRCan, CFS, Ottawa, for her comments and suggestions during the editorial process.

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Executive Summary

The forest products sector contributes significantly to the Canadian economy. Historically, Canada's rich natural resource base with its low-cost and high-quality raw materials has provided its firms with a comparative advantage in the marketplace. Canadian forest products firms dominate the global market without having to resort to developing and employing new, expensive, untested technologies. Technological change has been manifested through construction of new integrated processing complexes permitted by the expansion of harvesting into new, previously undeveloped forest areas. However, the situation is changing. Costs of raw materials are increasing in Canada and decreasing in competitor countries. The opportunity to modernize through expansion is declining. The quality of Canadian fibers in products such as pulp and newsprint is becoming less of a competitive advantage. The net effect of these trends is an erosion of Canada's traditional advantage: abundant resources. If the Canadian forest products industry is to remain a world leader in the export of forest products, alternative strategies to maintain competitiveness will be required.

The future ability of Canadian firms to access foreign markets may increasingly depend on the knowledge content of products, that is, the amount of scientific information or knowledge embedded in one product compared with another. Increasing the knowledge content of the Canadian product mix will require a more aggressive approach to R&D and to technological innovation by firms together with support and encouragement from governments.

A number of conditions need to be satisfied before enhanced commitment to R&D and innovation initiatives by the private and public sectors are justified. There must be a rational basis for justification of increased expenditures (for example, profitability, strategic objectives, improved social welfare, stability of rural communities) and assurance that investment will result in a real impact (that is, that the institutional framework is effective and efficient). A review of the incentive structure for innovation and the institutional framework that governs, manages, and facilitates innovation must be undertaken. The role of technology in the forest products industry must be redefined, the viability of various options assessed, and concrete and effective actions by firms and governments implemented.

In this study we identify various issues, challenges, policy questions, and options relative to assessing and redefining the role of technology in Canadian forestry. A summary is provided below:

Recognition of common concepts: One of the first steps towards redefining the role of technology in the forest products industry will be to develop a common framework for evaluating innovation and for assessing options. Models based on a flow of information from basic to applied research through to commercial application are no longer adequate. More recent methods, such as the feedback model of innovation, are available and should be applied to evaluate issues in the Canadian forest products sector.

Inherent bias to the high technology sector: The resource sector must deal with an inherent bias towards the high technology sector in the Canadian R&D establishment. The "high tech" sector is exciting, high profile, and urban-based, requires highly skilled individuals, and provides high-paying jobs. For these reasons most developed countries are attempting to promote high tech within their economies.

It can also be argued, however, that technology has a relevant and increasing role to play in traditional industries. Some countries (such as the United States, Sweden, and Finland) have pursued opportunities to develop technology niches by focusing S&T activities on their forest industries. A similar strategic focus on the development of technological opportunities in Canada's forest industry is not evident. The Canadian forest sector should identify, articulate, and communicate the opportunities inherent in enhancing the technological capacity of the industry to senior decision makers and policymakers in Canada's S&T establishment.

Adequacy of R&D funding: R&D funding levels, funding mechanisms, and investment incentives should be reviewed and objectively assessed. Higher funding should be based on expectations of profits or social net benefits, ability to achieve specific and explicit strategic or social objectives, and ability of the R&D system to allocate resources efficiently to produce maximum gain. At the same time, funders and performers should recognize the risk involved in R&D and be prepared to accept that only a certain proportion of such activity will lead to commercial application.

Countervailing policies and regulations: Some environmental, social, and resource management policies may have a negative impact on the incentive of firms to upgrade capital by investing in production technology and product development. There should be explicit recognition of the impacts of new policies on the technological capacity of firms.

Structural barriers: Many market-oriented structural barriers to R&D in forestry exist. For example, inelastic demand for forest products, small firms, unconcentrated industrial structures, and cyclical markets reduce the inclination of firms to invest in technology. Options for mitigating these effects include product differentiation, encouragement of mergers and acquisitions, establishment of long-term funding mechanisms (such as R&D endowments), and encouragement of strategic alliances between small numbers of firms.

Role of governments: The new models of innovation suggest that governments have a role to play in the innovation process, but there is a need to ensure accountability and flexibility in government initiatives.

Role of research cooperatives: The new models of innovation also make a strong case for research cooperatives. Such cooperatives provide the sector with strategically important knowledge and technology to deal with generic, industry-wide, pre-commercial technology issues. They also serve as technology gatekeepers, facilitate technology transfer, and in some cases, provide technological assistance to individual firms. The research cooperatives are not, however, a substitute for in-house R&D by firms.

Role of universities: The strengthening of linkages between science and technology suggests a growing role for universities in the innovation process.

Complementarities within the R&D establishment: The knowledge generated by the various performers in the R&D establishment is complementary. For example, private sector R&D at research facilities and at mills, R&D at cooperative research institutes, forest resource related S&T by provincial and federal governments, and scientific research at universities contribute to the overall spectrum of knowledge requirements in the forest sector. The challenge is to ensure that these performers are linked, that R&D is coordinated, and that the cumulative impact relative to the stock of usable knowledge is maximized.

Diversity of firms, fiber resources, and consumer needs: Firms have unique needs and capacities. S&T policies in the forest sector will need to accommodate and reflect this diversity. The inherent characteristics of Canada's fiber resources are also highly variable. More effort is required to analyze the properties and characteristics of fiber under the variety of growing conditions in Canada's forests and to understand how management methods affect these properties and characteristics. To develop a meaningful and successful technological approach, industry must develop closer ties with consumers to understand their diverse and changing needs and preferences. The challenge ahead will be to match the features of a diverse resource base with the diverse needs of consumers through a diverse group of firms.

The workforce: A highly skilled workforce is necessary for receiving and implementing technology. Studies suggest that in Canada there is a gap between the skill requirements of a knowledge-based forest industry and the skill availability. There is also a gap between training requirements and training capacities. Enhancing the innovation performance of firms will be difficult without increasing the skill level of the forestry workforce.

Introduction

It began four million years ago with a gleaming black monolith — an inexplicable apparition that ignited the spark of human consciousness, transforming ape into man.

Book cover, Arthur C. Clarke's *3001: The Final Odyssey*

The forest products sector contributes significantly to the Canadian economy. However, most experts agree that the Canadian forest products industry is technologically conservative. Historically, Canada's rich natural resource base and the resulting low cost raw materials allowed Canadian firms to dominate the global market without having to develop and employ new, expensive, untested technologies. This trend may not continue.

Future access to foreign markets may depend more and more on the ability of Canadian forest sector firms to increase the knowledge content[1] of their production processes and products (Binkley 1993). The private sector may thus need to be more aggressive in its approach to technological innovation and make a greater commitment to research and development (R&D) in this area. Public agencies may also have to reconsider their design and delivery of science and technology (S&T) policy and programs.

The issues involved in assessing and redefining the role of technology in Canadian forestry are complex; the variables, options, and possible outcomes are numerous; and the risk and uncertainty associated with investing in technology or pursuing a particular institutional design pathway is considerable. We need to understand the changing role of technology in society, the properties of knowledge, the process of innovation, and the motivations for technology development and innovation by various organizations. As well, we must determine the factors affecting the innovation process in the Canadian forest products sector, the existing S&T system in Canada, future technological requirements of the sector, and ways to enhance the knowledge content of its products.

In this report we synthesize current information and expert opinions pertaining to technological innovation and competitiveness and provide an assessment of the technological performance of the Canadian forest products sector. The information supports and complements the CCFM's Criteria and Indicator Framework[2] as well as various other initiatives pertaining to forest-related S&T such as the *National Forest Science and Technology Course of Action* (CCFM 1998).

The Issue

A number of authors describe the emergence of a new techno-economic paradigm that is having significant effects on industrial organization and the distribution of production regionally, nationally, and globally. This paradigm suggests that not only are new concepts required but new types of policy interventions are necessary relative to the role and management of technology in society. Some of the more important conclusions of this research are that knowledge intensity of products is an increasingly important determinant of competitiveness (Lipsey 1993), that tacit knowledge and incremental improvements on the production line play a key role (Nonaka and Takenchi 1995), and that institutional design does make a difference (Lipsey 1993).

These findings and conclusions are relevant and applicable to the Canadian forest products sector. The future competitiveness of the Canadian forest industry may depend on a change in competitive strategy and approach. The knowledge intensity of Canadian forest products will need to improve

[1] The "knowledge content" or "knowledge intensity" of a product or processing technology is an abstract concept for describing the relative amount of scientific information or knowledge that is embedded in one product compared with another. For example, the knowledge content (or intensity) of a modern car is higher than the knowledge content of the Ford Model T; the knowledge content of newsprint from a modern high speed newsprint machine is higher than that from older and slower newsprint technology; the knowledge content of the space shuttle is higher than that of a jumbo jet.

[2] The information provides an improved basis for interpretation of Indicator 5.2.3 ("trends in R&D expenditures in forest products and processing technologies") of the CCFM's Criteria and Indicator Framework (CCFM 1997, p. 90).

if the Canadian forest sector is going to maintain its position as the world's leading exporter (Binkley 1993). This conclusion is based on consideration of a number of concurrent forces affecting Canada's export performance:

- Reduced opportunities for industry expansion into undeveloped and unallocated forest and the transition from old growth forest to second rotation forests.
- Increased integration of the global economy through trade, financial transactions, the development of global institutions, and enhanced telecommunications.
- Maturing of the U.S. and European markets, which account for the majority of Canada's forest product exports.
- Increasing cost of production in Canada due to a combination of increasing fiber costs and regulatory requirements.
- Increased production and exports from producers in Indonesia, Malaysia, Chile, New Zealand, and Brazil, who have a comparative advantage in wood and labor costs and location advantages relative to growth markets in the Pacific Rim.
- An increasingly complex and competitive market environment within which consumers are demanding high quality products at competitive prices as well as product differentiation, timely delivery, and assurances of sustainable forest practices.
- Transition of Canada's economy to a knowledge-based economy.

The combined effect of these trends and forces will be increased competition from nontraditional suppliers in emerging markets, increased competition from domestic suppliers in traditional export markets (the United States and Europe), increased cost per unit of raw material inputs, and a decline in the importance of Canada's traditional source of comparative advantage (that is, abundant, relatively low-cost, high-quality fiber resources). Thus, the issue for Canada is not disappearing forest but probable gradual decline in ability to access foreign markets. This conclusion assumes that other competitiveness factors (including technology, labor and energy costs, environmental regulations, forest policies, exchange rates) remain unchanged. The one factor that is somewhat within the control of firms (and governments), and which may be strategically managed to counter erosion of our traditional comparative advantage, is technology. Enhancing the knowledge content of Canada's product mix provides a way of differentiating Canadian forest products from those of competing countries.

Technology provides options to improve the technological performance of the Canadian forest sector; it is not a panacea. A technological strategy must address many complex issues including the economic viability and social desirability of increased private and public sector investment in R&D and innovation; the institutional re-engineering required to establish an incentive structure that encourages technology development and innovation; and the types of organizational structures that will maximize the productivity and efficiency of forest sector science and technology systems. In this study, we intend to define and clarify these issues and to provide information that supports the process of defining and evaluating options and approaches.

The Approach

This report provides a synthesis of current information and expert opinion pertaining to technological innovation in the Canadian forest products sector. The information and analysis in this report is based on four sources of information: academic research on the properties of knowledge and technology and its relationship to economic growth and industrial development; previously published research and analysis on the status and importance of science, technology, and innovation in Canadian forestry; interviews with experts in forest sector technology in forestry firms, cooperative research institutes, and selected government agencies; and qualitative and quantitative evidence on forest sector innovation performance. Interviews were not conducted with corporate executives and therefore their perspectives are not reflected within this report.

Impacts of Technology on Society

Knowledge itself is power.
Francis Bacon

Technological progress allows society to extract a higher value of output for the same value of input. It does more than simply raise the level of output available for consumption. It transforms peoples lives through the introduction of new goods and services and new ways to do things. It thus expands significantly the possibilities open to individuals as both producers and consumers.

Social critics point out that technological progress is often accompanied by rapid obsolescence of assets and skills, disruptions of communities, labor dislocation, and social instability. It upsets some established ways and makes, at least in the short term, losers of those whose skills and assets become obsolete. There is little disagreement, however, on the importance and scope of the impact that technology has on our lives. Technology affects industrial competitiveness and structures, environmental quality (sometimes positively, sometimes negatively), living standards, cost of living, working conditions, social cohesion, health and welfare, entertainment and recreation, transportation, and communications (Mansfield et al. 1977). The capacity to bring about and manage technological progress empowers a country to exert more control over its destiny, increasing the choice of options it can offer its citizens.

In this chapter we examine the process of technological innovation and technology's role in and impact on society. We hope to provide the reader with a general understanding of the innovation process in the Canadian forest products sector, of the evolving role of technology in society, and of the complex interrelationships between technology and growth, competitiveness, employment, and environmental quality.

A Source of Economic Growth

According to neoclassical economic theory, economic growth depends on technological progress, trade, and population growth. In the short term, growth can be achieved without these elements by increasing capital through savings. In the long term, diminishing returns to capital will eliminate growth (Solow 1956). Thus, economic growth requires technological change. Nelson (1994) supports this view; he argues that technological progress is not simply *a* source of growth in the economy, it is *the* source of economic growth.

However, all researchers do not agree on the nature of the cause-effect relationships between R&D, technological progress, productivity, and economic growth. Some have been unable to empirically demonstrate the existence of a relationship between R&D and productivity growth. Pack (1994), for example, points out that countries such as Japan, whose R&D grew rapidly in the post-war period, were subject to the same slowing in productivity growth as countries whose R&D grew more slowly. The lack of a relationship between R&D and productivity is referred to as the "Solow Paradox" (Gibbons 1995).

There are several possible explanations for the apparent lack of a strong relationship between expenditures on R&D and productivity growth at the national level. Although R&D can be viewed potentially as an important trigger of technological change, especially when important breakthroughs occur, the production system must be reorganized and the social system must adapt to bring about productivity changes. It takes time to refine and implement new technologies. Indeed, it may be those (outside the country) able to absorb the technology faster and adapt their production system more effectively who benefit from new technological ideas, not necessarily the creators of the new technology.

The Innovation Process

Theoretical research on innovation processes is providing an improved understanding of the characteristics and features of knowledge and technology, of the relationship between technological change and growth, and of the motivating factors and determinants of technological change (Boyer

1993; Gibbons 1995; Lipsey 1993). Some of the main findings of this research include the following:

Technological innovation is endogenous: Technological innovation is not determined outside the economic system (exogenous) as is assumed in the neoclassical growth model. The development of new technology is costly and risky. Investment in R&D is motivated by an expectation of some form of resulting benefit (or profit) that will exceed the R&D cost. Thus, technological innovation occurs in response to various economic signals such as prices, input costs, and profits and is endogenous to the economic system (Lipsey 1993).

Accepting that technological change is endogenous significantly affects our understanding and strategic management of the innovation process. We need to emphasize the fundamental role of the marketplace in developing knowledge and technology and the effects of economic incentive structures, market structures, institutional setting, and strategic investment behavior of firms on innovation performance.

Many factors influence the innovation investment behavior of firms in a particular industry sector. Hyde et al. (1989), for example, notes that firms in industries with inelastic demand and elastic supply feel they must pass the benefits of technological improvement through to consumers without retaining any of the benefits (or monopoly profits). Consumers benefit because of reduced prices but firms have difficulty capturing monopoly profits. Thus, firms in such sectors tend not to invest in developing new technology and are more often "technology-takers". Their innovation strategies involve the acquisition of technology embodied in purchased machinery and equipment. The various factors that influence the rate of development and innovation of new technology in the forest sector are described in more detail in Chapter 4.

Innovation supports competitiveness: Innovation is increasingly important for obtaining and preserving the competitive advantage of exporting firms in developed countries. Canada, for example, has a small, open, high-wage, resource-based economy that depends on exports (many of which are commodity products). Telecommunications, investments, and technological change are improving the capacity of developing countries (with low labor costs and abundant resources) to export commodities into the global market. Developed countries still maintain some advantages such as product quality, proximity to their markets, and ties with traditional customers, but they may find it increasingly difficult to compete on the basis of price with low-wage countries in undifferentiated commodity markets.

Consumers demand differentiation: Technological innovation can assist firms to differentiate their products, better match their outputs to specific customer requirements, and develop niche markets. For Canadian forest products firms to compete with low-cost suppliers, more product differentiation may be required.

Appropriation of the benefits of new technology by foreign countries affects social welfare: It is difficult to control, prevent, or limit the use of knowledge and technology. The tendency for knowledge and technology to "spillover" from firms, sectors, and countries to other firms, sectors and countries deters investment in R&D for technology development. On the other hand, society may benefit from this knowledge spillover. Policymakers must find a way to balance these two apparent conflicting interests.

Firms are diverse: Significant variation in innovation performance exists between firms within a particular industry. Many factors contribute to differences in the rate of innovation and to the innovation strategies used. These factors include R&D capacity, technology culture and receptiveness, skills of employees, price of inputs, vintage of existing machinery and equipment, and capacity to learn-by-doing (Arrow 1962).[3]

[3] Arrow (1962) was the first to suggest that an important source of technological progress was through a process of learning-by-doing. Learning-by-doing results in incremental improvements at a plant level that allow the firm to adapt a technology to local conditions and sometimes to refine, enhance, and improve a technology or to more effectively combine the new technology with the existing technology in the plant. This form of knowledge is generally not codified and is less subject to spillover effects. The knowledge can, however, be lost or transferred through the movement of employees.

Market structure is an important determinant of the rate of innovation: Market and industry structure (for example, level of competition in the marketplace, monopoly, oligopoly, industrial integration, firm size, and plant size) affects innovation and vice versa. Schumpeter (1950) suggests that in sectors where there are economies of scale in R&D, the relative size of firms and the degree of their dominance of particular markets are important factors.

Institutions greatly influence innovation performance: As noted previously, technological innovation is endogenous to the economic system and responds to economic signals such as prices, profits, and changes in input costs. However, private sector firms are not isolated entities in society. Consumers, producers, special-interest groups, and governments interact and interrelate through both market-oriented and nonmarket-oriented institutional structures or frameworks. The underlying purposes and mechanisms associated with these institutional structures can greatly influence the behaviors and the types of decisions made by households, firms, and governments. Differences between countries in the innovation performances of their firms can largely be explained by differences in their national institutions (Gibbons 1995; Lipsey 1993).

The linkage between science and technology is growing: The linkage between scientific research and technology development and innovation is becoming stronger (McFetridge 1995). The majority of new product and process innovations in today's modern economy originated from the application of scientific findings and discoveries. The growing integration of science and technology has resulted in shorter product life-cycles, higher initial product and process development costs, and increases in the level of risk associated with innovation investment (Lipsey 1993). The strengthening of this linkage is also a factor in the growing importance of S&T networks in encouraging innovation; in the blurring of the roles of governments, universities, industry, and research cooperatives with respect to funding or performing scientific, precommercial, and commercial research; and in the ability of firms to fully appropriate the benefits of research and development.

The feedback model of innovation is superior to the linear model for describing innovation processes: The linear model of innovation is being displaced by the feedback model to describe and characterize the process of innovation. The feedback model recognizes the role of users in identification of research needs, priorities, and funding and the importance of information feedback among researchers, producers, consumers, and governments during the knowledge creation and innovation process. The feedback model has significant implications for how analysts perceive the process of innovation, for the role of the private sector in open science,[4] and for the role of public agencies in pre-commercial and commercial R&D (McFetridge 1995). Because the feedback model is an important development in our conceptual understanding of the process of innovation within society, it is described in more detail in the next section.

Linear and Feedback Models of Innovation

The linear model of innovation assumes that scientific research is motivated by the search for knowledge not by commercial requirements; that in-house industrial R&D must be strictly protected for the exclusive benefit of the company developing it; and that the incentive for participation by the private sector in basic research and by scientists in activities with potential commercial application is limited. Thus, the linear model of innovation involves a relatively structured process whereby information flows sequentially from basic research (or in-house R&D) to applied research to commercialization, with limited interaction on decision making between each step (McFetridge 1995).

About 20 years ago, informed observers began to challenge the fundamental assumptions of the linear model of innovation because of changes in both the process and the understanding of innovation.

[4] Over time a self-regulating scientific reward and verification system has evolved, the purpose of which is to ensure that priorities for publicly funded research are not influenced by rent-seeking behavior; that research findings are promptly disclosed; that redundancy is minimized; and that research findings can be replicated and verified. Scientific activities performed under this system are described as "open science" (Dasgupta and David 1994).

A new innovation process model emerged called the feedback model. In this model the innovation process is cumulative, interdependent, and interactive, and is stimulated by

- incentives for private participation to expand the stock of open science knowledge and thus to fund research through, for example, cooperatives and foundations;
- the significant externalities and social benefits associated with the outputs of precommercial and commercial research and a stronger role for government in encouraging such research to adjust for market failures in research funding;
- the growing linkage between science and technology and the decrease in the degree to which they can be distinguished ("basic research" has no meaning in the context of the feedback model of innovation);
- strategic alliances between firms, industry-wide research cooperatives, and cooperative alliances among academic institutions, government research agencies, and the private sector;
- the use of infra-technologies[5] in open science and private sector R&D;
- practitioners, users, and consumers feeding knowledge and information back to researchers, scientists, research managers, and technology and knowledge developers;
- incremental improvements to existing technologies; and
- the development of technology partnerships with universities, governments, producers, and customers and information exchange and feedback between these groups (McFetridge 1995).

Benefits of R&D to Firms

Firms can benefit by investing in R&D in two ways.[6] First, they can reduce their production costs or improve product quality relative to other firms. Second, they can introduce new products (that do not have substitutes) into the marketplace (Fortin and Helpman1995). In both instances the firm is able to earn monopoly profits for a period of time. The ultimate determinant of the amount of research expenditure that would be justified by the firm is the level of activity where the cost of the last unit of research capacity (marginal cost) is equal to the marginal revenue product. The marginal monopoly profit revenue product in turn depends on the number of years that the firm can continue to derive monopoly profits from its new technology by preventing other firms from using or exploiting the technology. The longer that firms can prevent other firms from using their technology, the greater the payoff is and the higher the incentive is for firms to invest in R&D.

As previously noted, consumers demand product differentiation and are prepared to pay a premium for products they feel provide some higher level of satisfaction than traditional ones. Technological innovation allows firms to differentiate products and capture the associated monopoly profits. The benefits of product differentiation to firms are not limitless. Effects of scale can influence the optimal level of investment. Where there are constant returns to scale in R&D, continued expansion of the variety of products gradually reduces monopoly profits until the marginal revenue from introducing a new product is equal to or less than the marginal cost of adding new research capacity. Increased product differentiation becomes uneconomical. However, if the productivity of R&D increases with cumulative R&D (that is, increasing returns to scale), introducing new products will continue to be economical; this trend continues as long as the decline in the cost of R&D per innovation is sufficiently large enough to offset the decline in marginal revenue from introducing the new product (Acheson and McFetridge 1996; Howitt 1996).

Firms must be able not only to develop new products but also to market them. Marketing can differentiate products even when most of their attributes are similar. Levin et al. (1984) find that for most industries lead times and learning-curve advantages,

[5] Infra-technology refers to methodologies, databases, measurement and test methods and procedures, systems for information retrieval, analysis, and exchange (McFetridge 1995).

[6] This paragraph concentrates on the economic motivations for firms to innovate. Three other factors are involved in the decision of firms to innovate: precipitating conditions, enabling conditions, and corporate culture or attitudes (see Baker 1979).

combined with complementary marketing efforts, appear to be the principal mechanisms through which firms can appropriate their monopoly profits from innovation.

Social Welfare

Consumers are affected positively by technological change when they have new choices of products or they can buy existing products at lower prices. Domestic firms benefit when the technology developed by one firm spills over or is appropriated by other firms. However, technological change can also result in obsolescence of some products, failure of firms that produce the products, and unemployment for workers who suddenly find themselves with unmarketable skills. The social welfare of the country improves if the net benefits to innovators and consumers exceed the costs to industries and firms that have lost because of the innovation (Fortin and Helpman 1995). When an industry is a significant exporter, consumers in foreign countries benefit from the lower prices or higher quality goods; these benefits should not be included in assessments of the effects of innovation on domestic social welfare.

Employment

The industrial paradigm of the 1980s and 1990s is built around the shift to knowledge-based production, the falling costs of transportation, and a communications revolution arising from the relatively cheap, efficient transmission, retrieval, and analysis of data (Lipsey 1993). This trend has contributed to a rapid increase in the mobility of capital and to economic globalization. Firms purchase source materials and relocate laborintensive production wherever costs are lowest. However, those producing knowledge-intensive products tend to situate in areas where the knowledge base of the workforce is particularly high. The net effect of these trends will be reduced opportunities for unskilled labor in the high wage economies of Canada and the United States (Lipsey 1993).

The Canadian forest products sector has remained competitive in the face of rising labor costs by the adoption of labor-saving technologies. This practice, however, has resulted in the substitution of capital for labor. Although wage rates remain high and production levels have increased over the last 20 years, employment on average in the forest industry has stayed constant. Thus, technological change has had opposing effects on employment in the Canadian forest products sector: it has reduced labor requirements per unit of outputs, but by allowing the industry to remain competitive, it has maintained jobs and high incomes.

The Environment

The relationships between technological change, economic growth, and environmental quality are multidimensional. Some argue that the current rates of economic growth are unsustainable. If technological change is one of the key sources of economic growth, then technological change may also result in environmental degradation. An alternative view is that technology, economic growth, and environmental quality are complementary. The creation of wealth provides opportunities to invest in research and to develop technological solutions to environmental problems.[7]

Some aspects of economic development can result in environmental damage. The social benefits of development may or may not outweigh the environmental costs. The overall impact of growth on the environment depends on social choices regarding the balance between the social benefits of development and what society can accept in terms of environmental impacts or what society is prepared to pay to prevent or minimize these impacts.

The imposition of environmental regulations can directly and indirectly affect the cost structure and future competitiveness of firms. Fixed and variable costs to a firm may increase because of the need for more capital, labor, and materials to reduce environmental impacts of a particular

[7] Goods with income elasticities greater than one are called "luxury goods" and goods with income elasticities less than one are "necessities". In economics, the demand for environmental quality is classified as luxury goods in that an increase in income results in a proportionally higher percentage increase in the demand for environmental quality.

production process—a direct effect. However, a firm may be indirectly affected by its ability to develop and innovate new processes or new products. If R&D resources are redirected from finding new process technologies and products to developing environmental technologies, then the capacity of the industry to respond to competitive challenges and changes in relative input prices may decline.

Mitigating Scarcity

In neoclassical economics there are no limits to growth (Stiglitz 1979). The price of a country's resources depends on availability and abundance relative to demand. The more abundant resources are and the lower the demand, the lower their price. As resources are used, their supply shifts, and their market price tends to increase. Increasing prices for the resources lead purchasers to either reduce their rate of consumption, substitute the resource with other inputs (usually by developing new technology), or find new sources of supply. Thus, according to neoclassical economic theory, market prices and technological change are dominant forces relative to the ability of society to adjust to the changing availability of its natural resource base. In forestry, price (or cost) increases have led to technological changes that have improved the efficiency of resource use; examples are the development of lightweight papers and medium-density fiberboards, processing systems that improve lumber recovery, and better use of roundwood through the production and sale of wood chips by sawmills.

Technological Capacity of the Forest Products Industry

A wise man will make more opportunities than he finds.
Francis Bacon

In this chapter we assess the technological capacity of the forest sector and describe some approaches for evaluating the adequacy of R&D funding.

The technological capacity of the forest industry can be seen as a measure of the ability of firms to increase the knowledge content of their processes and products by developing and/or receiving new technology and knowledge. Measuring or assessing technological capacity is complex because firms increase knowledge content in a number of different ways. For example, they may develop and commercialize new products and processing technologies internally; purchase and adapt new technologies developed by other firms or external research agencies; imitate, replicate, copy, or appropriate technologies and techniques developed by others; and/or incrementally improve, enhance, and/or refine existing technologies at the processing site. The knowledge embedded in processes and products is in some cases codifiable (that is, can be documented and copied by others). In other cases the knowledge is tacit and embodied in the expertise and experience of employees and cannot be measured.

One approach to measuring technological capacity is to consider innovation as a process leading to certain outcomes, such as higher productivity, increased market share, improved profitability, better environmental protection, improved competitiveness, or improved resource management performance.

Another approach is to focus on evaluating the inputs to innovation. Important inputs are the existing stock of relevant knowledge, R&D expenditures by firms and governments, the number of researchers employed by firms and governments, the level of scientific and technical training of human resources, the technological receptiveness of firms, and a favorable institutional environment that rewards investment and encourages feedback and interactions between researchers, plant managers, executives, policymakers, and customers. Assuming these inputs are effectively used, the direct output of innovation is an increase in the knowledge intensity of products, processes, technologies, and management techniques.

Some alternative measures of the benefits (or outputs) of innovation include net returns to R&D capital, increases in net social welfare (measured in consumer and producer surpluses), decreased cost of production, patenting, higher productivity, monopoly profits, improved market share, elimination of rival firms, reductions in effluents, increases in financial performance of firms, and reduction in prices for domestic consumers. This list, although not exclusive, shows that the motivating factors behind decisions to invest in R&D are complex, multidimensional, and vary considerably with the perspective of the funding organization.

Canada's Technological Capacity

On a per-capita basis, Canada spends significantly less on R&D than other OECD (Organization for Economic Co-operation and Development) countries (Table 1). Four important factors distinguish Canada's overall commitment to R&D from other OECD countries (Table 2): in Canada the percentage of business-oriented R&D accounts for significantly less (0.82 % vs 1.51 %) of the total GDP (gross domestic product), the percentage financed by industry is

Table 1. Gross per-capita expenditure (current purchasing power parity dollars) on R&D in Canada, the United States, Sweden, and OECD countries, 1993.

Country	Gross domestic per-capita expenditure on R&D ($)
Canada	289.3
United States	659.0
Sweden	525.2
European Union	334.4
Nordic countries	415.6
OECD average	400.3

Source: OECD (1995).

Table 2. Comparative indicators of science and technology activities: Canada versus OECD countries.

Indicator	Canada (%)	OECD avg. (%)
Gross expenditure on R&D (GERD) as a percentage of GDP (1993)	1.5	2.2
Percentage of GERD performed by the business enterprise sector (1993)	54.4	67.4
Business enterprise expenditure on R&D (BERD) as a percentage of GDP (1994)	0.8	1.5
Percentage of BERD financed by industry (1991)	72.2	82.4
Percentage of BERD financed by government (1991)	9.8	14.9
Percentage of BERD financed by foreigners (1991)	18.0	NA[a] for OECD. EU = 7.6%. Nordic countries = 2.7%.

Source: OECD (1995).

[a] Not available.

lower, the percentage funded by government is lower, and the percentage funded by foreigners is much higher. Ironically, Canada's overall commitment to business-oriented R&D would be even lower than other OECD countries if it were not offset by funding from foreigners.

Technological Capacity of Canada's Forest Products Sector

The R&D intensity (expenditures on R&D as a percentage of sales) by Canadian firms in the pulp and allied products sector is considerably lower than that of firms in other countries. Producers of paper and allied products in the United States spend about 1.1% of their net revenues on R&D (NSF 1995); producers of pulp and paper products in Japan spend about 0.9%. R&D intensity in 1994 by the four largest Swedish firms ranged from 0.6% to 1.4% and by the five largest Finnish firms from 0.5% to 1.0% (Lindstrom 1996). Statistics Canada reports intramural R&D as a percentage of performing company revenues to be 0.4% or lower for Canadian firms in the pulp and paper industry (Lindstrom 1996).[8]

The relatively lower spending on R&D in Canada is paralleled by a relatively lower employment of R&D personnel by the forest industry. In 1993, the total number of R&D person-years for the Canadian forest-products industry (defined as the wood and paper and allied industries) was around 1 200 (Statistics Canada, various years, Cat. No 88-202-XPB [1993]). The comparable U.S. industry employed over 12 200 full-time equivalent scientists and engineers (National Science Foundation web site). Total employment in the U.S. and Canadian forest products sectors (logging, wood industries, paper and allied) in 1993 was 1 447 000 (U.S. Bureau of Statistics web site) and 254 000 (CFS 1996a), respectively. Thus, in 1994 the ratio of forest sector employees to researchers was 119 to 1 in the United States and 212 to 1 in Canada.

The use of R&D expenditures or ratios of researchers to total employment to measure innovation performance is controversial and can be misleading (Bernstein 1991). Firms rely on a number of approaches to innovate and improve technology that may not involve the development of technology. Also, R&D expenditures are inputs to, and not outputs from, the innovation process. An assessment of the innovation performance of Canadian companies should also consider output measures. One such measure is patenting.[9]

Table 3 shows the number of registered Canadian and U.S. patents by nationality of patent holder from 1990 to 1996. The total number of patents registered in the United States in 1996 for paper and

[8] The paper and allied industries are relatively more research intensive than the wood industries. R&D expenditure as a percentage of the value of shipments averaged 0.14 between 1987 and 1994 in the wood industries and 0.475 in the paper and allied industries over the same period (Statistics Canada, various years, Cat. No. 88-202-XPB; CFS 1998).

[9] The use of patent data to assess innovation performance is controversial; see Globerman (1997) for a critique of the use of patent statistics as measures of innovation intensity. We use a broad range of measures in this study, including input and output measures. We believe that this broad group of indicators provides a reasonable approximation of the innovation performance of the Canadian forest products industry.

Table 3. Distribution of Canadian- and U.S.-registered patents in the paper products and paper-making categories (International Class D21) by home country of firm and year of registration.

Home country of patent holder	1990	1991	1992	1993	1994	1995	1996
Canadian-registered patents							
Canada	8	12	13	7	6	7	7
United States	52	57	46	56	42	48	55
Finland	21	18	18	21	12	20	16
Sweden	26	14	12	15	12	10	4
Other	11	31	35	43	26	24	22
Total	**118**	**132**	**124**	**142**	**98**	**109**	**104**
U.S.-registered patents							
Canada	6	7	19	11	16	7	21
United States	174	177	214	196	169	187	207
Finland	50	34	39	27	17	26	43
Sweden	32	17	13	18	12	23	25
Other	103	83	93	121	119	111	116
Total	**365**	**318**	**378**	**373**	**333**	**354**	**412**

Sources: Canadian-registered patents: Canadian Patent Database, <<http://strategis.ic.ga.ca>>. U.S.- registered patents, Center for Networked Information Discovery and Retrieval <<http://patents.cnidr.org>>.

paper-making technology (412) is four times higher than the number of patents registered in Canada (104). In addition, Canadian firms account for a relatively small share of total patents in this segment of the industry in both Canada and the United States; for example, in 1996 Canadian firms held around 3% and U.S firms 49% of the total North American patents in the paper products and paper-making categories. In comparison, in 1993 Canada accounted for 29% of total North American production of wood pulp and 19% of North American production of paper and paperboard (CFS 1996a).

Another measure of capacity is the rate at which firms innovate technology through the purchase of new machinery and equipment. Unfortunately, information is unavailable for international comparisons. Studies suggest that Canadian wood products firms are slower than their competitors in adopting new externally developed technologies (Hayter 1987; Globerman 1976) and that the wood products and paper industries are slower than other industries in incorporating advanced manufacturing techniques in their operations (Baldwin and Sabourin 1993).

The vintage of the technological infrastructure also affects competitiveness and provides insight into technological capacity. The vintage of machinery and equipment in Canada's forest products sector varies widely. Significant expansion in the production capacity of the forest industry has occurred in some areas in the last 10–15 years. The technology embodied in these expansions is generally state of the art. However, at a national level, the technology used in the Canadian forest industry is on average older than that of its competitors. An example is the higher proportion of older, slower, and more labor-intensive machinery used by the Canadian pulp and paper industry (FSAC 1992). Moreover, in the future firms are expected to have fewer opportunities to expand by constructing new facilities in previously undeveloped areas.

Trends in R&D Expenditures

The 1988 Canadian Council of Forest Ministers' forum Innovation and Technology: Science in the Forestry Sector (CCFM 1988) described the changing competitive circumstances facing the Canadian forest industry and concluded that technological innovation would be a determining factor in the future success of the industry.[10] Thus, recognition of changes in the structure of the global marketplace and of the growing importance of innovation was identified in a national sector forum as far back as 1988. The CCFM forum provided a series of recommendations including the following:

> That industry and government commit to sustained R&D and technological innovation to strengthen sector competitiveness in world markets for Canadian forest products as well as to further develop export capabilities in knowledge, goods and services.

[10] Hayter (1987) also highlighted the relatively small amount of R&D performed in-house by Canadian forest products companies compared with companies in the United States, Sweden, Finland, and Japan and called for an increased commitment to R&D and innovation.

That industry must strengthen R&D linkages with Canadian equipment manufacturers and in collaboration with governments, reinforce R&D for new product development emphasising value added, more competitive processing, innovation and commercialization.

Tables 4 and 5 show trends in expenditures on R&D in nominal and constant dollars and therefore provide information to assess the extent to which the needs and priorities identified in 1988 at the CCFM forum were acted upon. Nominal R&D expenditures in the wood industry peaked in 1990 at $42 million and declined to an average expenditure of $22 million per year between 1991 and 1995. In the paper and allied industries, nominal spending peaked at $151 million in 1989 and averaged $101 million per year between 1991 and 1995.

Simple comparisons of trends in nominal expenditures over time provide a misleading picture of trends in real R&D capacity. Roberts (1991) showed that the cost of conducting R&D in the wood industry and paper and allied industry increased by 307% and 277%, respectively, between 1970 and 1987. Moreover, he found that the price of inputs in general (at the macroeconomy level) increased only by 219% over the same period. These findings have two important implications. First, trends in nominal dollars do not provide accurate information on trends in R&D capacity. Second, simple adjustments to R&D expenditures using standard deflators (such as the GDP-implicit price index) will understate the effect of cost increases on R&D capacity. An accurate view of trends in research capacity (based on expenditures) requires the development of a sector-specific R&D deflator. Statistics Canada has developed such deflators and they are used to adjust nominal dollars to real expenditures in Tables 4 and 5. With the exception of a few outlier years (which probably reflect one-time expenditures for large capital items), the level of R&D expenditures in real dollars has been fairly constant, averaging about $21 million per year (excluding 1990) in the wood industry and about $97 million per year (excluding 1988 and 1989) in the paper and allied industry. The flat trend in real R&D expenditures

Table 4. Trends in nominal and real expenditures on R&D in wood industries, 1987–1995.

Year	Nominal R&D expenditures ($, millions)	Real R&D expenditures (1993 $, millions)	
		GDP deflator[a]	Special R&D deflator[b]
1987	19	22.6	23.0
1988	20	22.8	23.9
1989	18	19.5	19.1
1990	42	44.2	42.9
1991	19	19.4	18.5
1992	20	20.2	19.6
1993	23	23.0	23.0
1994	24	23.8	NA[c]
1995	24	23.5	NA

Source: Statistics Canada (various years), Cat. No. 88-202-XPB.

[a] Deflated with the GDP-implicit price index (Statistics Canada, various years, Cat. No. 11-210 -XPB).

[b] Deflated with special R&D deflator indices developed by Statistics Canada (unpublished data).

[c] Not available.

Table 5. Trends in nominal and real expenditures on R&D in paper and allied industries, 1978–1995.

Year	Nominal R&D expenditures ($, millions)	Real R&D expenditures (1993 $, millions)	
		GDP deflator[a]	Special R&D deflator[b]
1978	33	68.6	74.9
1979	43	81.2	87.3
1980	52	88.8	95.5
1981	68	104.8	111.0
1982	62	88.0	91.6
1983	56	75.7	79.7
1984	64	83.8	85.6
1985	75	95.7	99.6
1986	89	111.0	115.1
1987	87	103.6	105.9
1988	145	165.0	169.5
1989	151	163.9	167.4
1990	112	117.9	119.5
1991	98	100.3	100.8
1992	94	95.0	96.7
1993	102	102.0	102.0
1994	102	101.3	NA[c]
1995	110	107.6	NA

Source: Statistics Canada (various years), Cat. No. 88-202-XPB.

[a] Deflated with the GDP-implicit price index (Statistics Canada, various years, Cat. No. 11-210 -XPB).

[b] Deflated with special R&D deflator indices developed by Statistics Canada (unpublished data).

[c] Not available.

indicates that the forest industry and government did not respond to the 1988 CCFM recommendations to increase the R&D capacity of the forest industry, especially in the pulp and paper industry.

Adequacy of R&D Funding

This section addresses the issue of adequacy of funding for R&D. We provide information and case studies on various types of quantitative measures that can be used to support the R&D budget evaluation process. However, we cannot, for reasons that will be discussed, say whether or not R&D funding is adequate.

Two main types of numerical measures are commonly used to assess adequacy of R&D funding. One approach is to estimate the economic return on R&D investment using various types of economic techniques to identify, quantify, and compare the appropriate benefits and costs. A second approach is to quantify the amount of money spent on R&D or the amount spent as a percentage of sales and then compare this value to some standard or benchmark.[11] Comparisons over time or between various competitors provide a subjective basis for evaluating funding levels. Both of these approaches have strengths and limitations.[12] Measuring the economic return to R&D investment is preferred on theoretical grounds; however, there are practical limitations associated with difficulties in fully and reliably quantifying the future benefits of R&D. Comparisons of R&D intensity are easy to derive, but they have limitations because they do not directly address the issue of whether R&D in a particular context is a worthwhile investment.

The above two approaches are useful and complement each other as long as their inherent weaknesses are recognized. Also, although they give useful insights into R&D funding adequacy, the two measures are not sufficient enough to be the sole basis for determining R&D budget levels. Additional considerations are necessary for the following reasons: the measures are estimates and subject to errors of estimation; R&D has wide-ranging direct and indirect effects on society, some difficult to identify or predict; the benefits of R&D are, in some cases, non-quantifiable and can only be discussed in qualitative terms; and R&D is inherently risky. Some projects will not result in usable results and others will; in many cases there is no way to predict which projects will succeed. A number of non-economic factors, including strategic and distributional considerations, also affect the process of determining, prioritizing, and evaluating R&D spending.

Because previous sections provide information on R&D spending, in the remainder of the section we will focus on methods for estimating the economic return to R&D in the forest sector by reviewing three case studies.

Study 1

Mohnen et al. (1996) use a variable cost function to estimate the returns to R&D econometrically for the Canadian wood industries and pulp and paper industries. They measure the benefits of industrial R&D in terms of reductions in the cost of production attributable to technological change. Their findings are summarized as follows:

- The wood and paper and allied industries are integrated but knowledge flow between the sectors seems limited.
- The gross real[13] rate of return to R&D is 11.6% in the pulp and paper industry and 17.8% in the wood industry. Assuming a 10% depreciation rate on fixed assets, the net real rate of return is 1.6% in the pulp and paper industry and 7.6% in the wood industry.
- Returns on investment are in the lower range of returns to R&D observed in other industrial sectors.

[11] Comparisons with other countries is often made by using the R&D intensity indicators, which is the amount spent on R&D as a percentage of sales or value-added or GDP or some other economic aggregate. Relative comparisons of R&D spending over time requires the use of appropriate deflators as was discussed in previous sections.

[12] Bernstein (1991) notes that comparisons of R&D intensity between countries is a misleading measure of adequacy. A propensity to spend does not ensure that the benefits of the investment justify the costs. Binkley (1993) uses relative rates of spending on R&D to argue that an increased commitment of financial resources to R&D is necessary if Canada is going to compete in the global marketplace.

[13] The real rate of return represents the return to investment after inflation is accounted for.

Mohen et al.'s low return on investment in industrial R&D in the forest products sector suggests that investments may earn a higher return in alternative uses. However, their returns on R&D investment are conservative or lower-bound estimates for the following reasons:

- R&D is represented in their function as a stock. The R&D stock is calculated using the "perpetual inventory method," which includes cumulative R&D expenditures and adjusts the stock for depreciation and additions in terms of new R&D investment. If all R&D expenditures through time were devoted to product and process development activities, the resulting R&D stock would be directly comparable to the returns to R&D (measured in the analysis as a reductions through time in average variable costs). However, in the case of forestry products sector R&D, a portion of the expenditures has been devoted to developing environmental technologies. These technologies do not necessarily improve the efficiency of the industry or its ability to reduce costs.[14] The net effect is to dampen the return on investment because the value (or social benefits) of the environmental quality enhancements are not reflected in the calculations of R&D benefits.
- Their analysis presumes that cost differences between two periods would be the same without the existence of the R&D stock. Investment in R&D essentially results in a lowering of average variable costs and this is built into the function as a shadow price representing the returns to R&D. The model does account for cost changes between periods resulting from price increases, but does not include increased costs due to quality shifts in inputs (such as wood). If the cost in period two would have been higher than the cost in period one without R&D as a result of declining raw material quality, then the benefits or returns to R&D are underestimated. Table 6 demonstrates this point using hypothetical data. The hypothetical case study indicates that if one uses the methodology adopted by Mohnen et al., the return to R&D would be $2. However, if costs would have actually increased over the period (because of the need to use smaller and more remote trees), the real benefits would be doubled or $4. An upward pressure on average variable costs in the Canadian forest industry, particularly with respect to wood costs, probably exists. This results in longer haul distances, a general decline in wood quality, higher stumpage, and increased costs arising from new forest practice requirements.
- Mohnen et al. measure the benefits of R&D with respect to average variable costs, implying that the R&D is primarily process development related. In reality, some R&D is related to product development and product quality enhancement. As indicated in Chapter 2, product-related R&D is strongly motivated by a desire to capture monopoly profits; thus some of the benefits of R&D will be associated with higher revenues. The methodology used by Mohnen et al. does not reflect research benefits resulting from higher revenues and do not capture these benefits in their model.

Table 6. Effect on estimates of return to R&D of assumptions about cost changes between periods, using methodology adopted by Mohnen et al. (1996).

Scenario	Hypothetical variable cost: In period 1 ($)	In period 2 ($): Without R&D	In period 2 ($): With R&D	Benefit of R&D ($)
1: Constant real cost between periods	10	10	8	2
2: Increase in real costs between periods	10	12	8	4

Study 2

Bernstein (1994) calculates private and social rates of return to paper and allied industries in Canada and the United States (see Table 7). With a 10% depreciation rate and a corporate tax rate of 46%, the net after-tax return on investment in the Canadian paper and allied industry is about 1.5% in real terms; this is comparable to the Mohnen et al.

[14] Price Waterhouse estimates that British Columbia wood and pulp and paper industries dedicated about 20% of total 1990–1996 capital expenditures to the purchase of machinery and equipment required to meet environmental regulations.

Table 7. Private and social rates of return on R&D in the paper and allied industries in Canada and the United States.

Type of return	Canada (%)	United States (%)
Private rate of return	12.79	18.52
Domestic spillover return	21.63	66.47
International spillover return	92.06	14.24
Social rate of return	126.48	99.23

Source: Bernstein (1994).

(1996) study. The social rate of return is 126% in Canada and 99% in the United States. The Bernstein study, however, reveals significant differences in the direction of spillover benefits between the Canadian and U.S. paper and allied industries. International spillover of Canadian R&D appears high and that of U.S. R&D relatively low. When only private and domestic spillover returns are considered, the social rate of return to paper and allied research is 34% in Canada and 85% in the United States. The U.S. government thus has a greater incentive to support and encourage R&D in the paper and allied industries than do provincial and federal governments in Canada.

Study 3

Hyde et al. (1989) have developed a series of econometric models to estimate the returns on R&D investment on various forest products sectors in the United States, including the softwood plywood, sawmill, wood pulp, and wood preservative industries. They also provide estimates of the return on investment to timber management and growth research for the U.S. Southern Pine Region. For this region, they find negative economic returns for publicly funded timber management research. However, Hyde et al.'s analysis of timber management and growth has marginal applicability to Canada because this area of research accounts for a relatively low proportion of total forestry-related research in Canada.

Their approach to estimating the benefits of forest products research differs somewhat from that used in the two previously described studies. Hyde et al.'s model estimates the supply and demand functions for the various forest products industry sectors. Research expenditures are an input to the production function and result in shifts in the supply function. The resulting system of equations can be used to measure changes in consumer and producer surplus associated with investment in R& D.[15] Hyde et al. find significant positive economic returns to public investment in forest products research; for example, the internal rate of return on public research investment based on consumer surplus benefits is 326 %, 34 %, and 33% in the softwood plywood, sawmill, and wood pulp industries, respectively. They conclude that from 1950 to 1980 forest product research was significantly underfunded (particularly for the softwood plywood industry).

One of the important social benefits of R&D is a reduction in price of products available to consumers and an increase in consumer surplus. Hyde et al. demonstrate that increased consumer surplus is a legitimate social benefit of R&D when evaluating the social benefits of R&D investment in the U.S. forest products industry. This may not, however, be the case for Canada, which exports a majority of its forest products. Lower prices would benefit consumers in other countries, and it is not appropriate to include such consumer surplus gains in estimating benefits of Canadian R&D.

Hyde et al. also examine whether public agencies should increase resources devoted to forest products research. They describe three situations where public spending on forest products research may be necessary to reach the socially optimal level of investment in R&D: where the R&D investment requirements exceed the capacity of most firms (that is, large initial investment required, long investment horizon, high uncertainty); where product demand is inelastic and supply is elastic (resulting in a tendency to transfer research benefits to consumer); and where the aggregate benefits (across all firms) justify the R&D investment, but no single firm is

[15] This study suffers from the same limitations as the other studies in terms of an inability to capture the benefits of product development. The studies discussed in this section measure the benefit of innovation in terms of shifts in the supply function. This approach limits benefit estimation to benefits associated with innovation of new process technologies and may result in a systematic downward bias in the estimates of return on investment.

able to support the R&D cost. They conclude that public investment in softwood plywood research in the United States over the period 1950–1980 was justified and that it was even underfunded. They emphasize that this does not necessarily mean that public support is justified for all forest products research. Differences in market circumstances, prevailing input prices, and various other factors mean that each situation needs to be evaluated separately.

The specific results of the Hyde et al. study have little direct application to current circumstances in Canada. The study does, however, illustrate a relevant methodology for assessing the adequacy of public funding for products related to R&D. It also shows the importance of developing some understanding of the underlying costs and benefits of research investment when determining whether public support is justified.

Main Findings

The three studies reveal the following concerning adequacy of funding:

- The flow of knowledge and technology between Canada's wood industry and paper and allied industry is relatively limited (Mohnen et al. 1996).
- The real rates of return on Canadian forest products research are relatively low compared with other industries in Canada. However, these rates are biased downward because the studies include the costs of developing environmental technology but not the benefits; do not consider monopoly profits related to new products as benefits; do not account for qualitative changes in inputs between measurement periods; and do not include strategic opportunities to invest in technology now in order to generate a future stream of benefits (Mohnen et al. 1996; Bernstein 1994).
- The social return on investment (excluding international spillover benefits) on R&D in the pulp and paper industry is 34% in Canada and 85% in the United States. The private return on investment is 13% in Canada and 18% in the United States (Bernstein 1994).
- Technological innovation results in reduced prices to domestic consumers; therefore, changes in consumer surplus are a social benefit of R&D and should be included in determining return on investment (Hyde et al. 1989). However, since the majority of Canadian firms are exporters, the consumer surplus benefits accrue to consumers in other countries and should not be included in the calculation of benefits in Canada. Only the portion of total gain in consumer surplus attributable to domestic consumers should be included in the determination of social benefits.
- A role for public sector involvement in forest products research may exist. Public support of forest products R&D should be evaluated and based on the circumstances of the sector, the social benefits accrued, the investment costs, and the strategic and social goals of governments (Hyde et al. 1989). Economic analysis can assist decision making, but should not be the only consideration.

Adequacy of funding for R&D is an important but complex issue that cannot be answered in this report. Instead we discussed and illustrated the kinds of measures, indicators, and economic analyses that can assist the process of determining the appropriate level of public funding for R&D in the forest sector.

Factors Affecting the Rate of Innovation in the Canadian Forest Products Industry

The greatest mathematicians, as Archimedes, Newton, and Gauss, always united theory and applications in equal measure.
Felix Klein

In this chapter we identify and discuss features and characteristics of the Canadian forest products sector and market that affect the industry's technological capacity and rate of innovation. We base the information on the results of interviews with technology experts in the Canadian forest products sector[16], other research we have undertaken, and a compilation of relevant published studies.

Summary of Factors and Elements

Market Factors
Cyclicality of markets
Elasticity of demand
Contact with consumers
Variability in product end-use conditions

Production Factors
Abundance of low-cost resources
Variability of raw materials
Education, skills, knowledge, and experience of the labor force

Industrial Organization Factors
Location
Size of establishments
Size of firms
Industrial concentration
Entry and exit barriers
Horizontal and vertical integration

Institutional Factors
Environmental values
Intellectual property rights protection
R&D tax credits
S&T policy, programs, and agencies
Cooperative research institutes
Public policies

Market Factors

Cyclicality of Markets

Generally, a successful R&D program requires a long-term, consistent, and substantive commitment of financial resources. However, the considerable cyclicality[17] of prices and earnings characterizing the forest industry makes it difficult for the industry to ensure continuity in R&D funding[18] (FSAC 1992). Moreover, cyclicality leads to instability and uncertainty. Short-term projects or initiatives tend to be favored over longer-term proposals in unstable and uncertain environments. In many cases, the development of radical new products or production processes in the forest sector requires periods of commitment exceeding one or two business cycles. If R&D funding cycles with corporate earnings or if researchers tend to focus on short-term problems, then the rate of development of new technology will be low.

Elasticity of Demand

The elasticity of demand for particular products influences the innovation performance of industries. Technological change results in a shift of supply along the demand curve (Fig. 1). The innovation of new technology results in a shift in supply ($\mathbf{S_1}$) to a new position ($\mathbf{S_2}$). When shifts in supply occur along an inelastic demand curve ($\mathbf{D_1}$), total producer surplus changes from the area defined by *abg* to *efg*. However, when the supply curve shifts along a more elastic demand curve ($\mathbf{D_2}$), the total producer surplus is the larger area defined by *cdg*. Therefore, the net benefits of technological change to producers are larger when product demand is relatively more elastic (area *cdg* > area *efg*). The reason for this finding is that firms in industries with inelastic demand tend to pass technology gains on

[16] The list of the experts interviewed is provided in Appendix 1. It generally includes those individuals within firms that are directly involved in R&D management and activities. Corporate executives in other areas were not interviewed. Their perspective, therefore, is not considered in this report. We recognize this limitation since it means that a strategic perspective on the role of R&D in the corporate strategies of firms is not reflected.

[17] For example, the net earnings of the forest industry were $2.1 billion in 1995 but the industry incurred losses of $1.1 billion in 1996. Note that "billion" in this publication means a thousand million.

[18] Cyclical markets were mentioned by a significant number of the forest sector technology experts as a factor affecting R&D. According to the experts, the highly cyclical nature of forest products markets makes it difficult for firms to sustain long-term funding commitments to R&D and innovation.

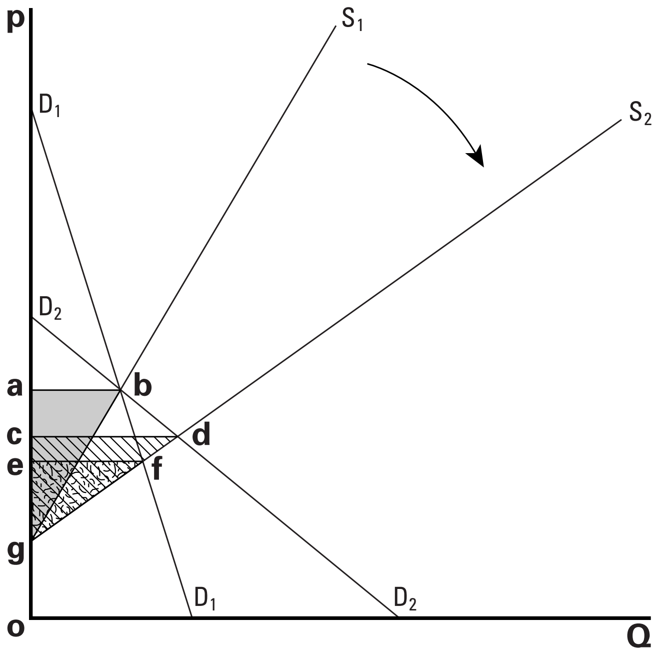

Figure 1. Effects of demand elasticity on producer gains from technological innovation, where **S** is supply, **D** is demand, and *abg* is producer surplus before shift in supply, *efg* is producer surplus after supply shift with inelastic demand, and *cdg* is producer surplus after supply shift with elastic demand; *o* = origin, *p* = price, and *Q* = quantity.

to consumers in the form of reduced prices. The total amount demanded, however, is relatively unresponsive to the price declines (Hyde et al. 1989).

The demand for lumber and plywood is generally viewed to be inelastic (Catimel et al. 1997; Hyde et al.1989). Thus, the ability of the private sector to capture the financial rewards from the development of new technology in these industries is lower than in industries with relatively more elastic demand. However, the benefits to consumers are higher when supply shifts along an inelastic demand curve. Socially beneficial impacts such as increased consumer surplus are an important consideration in cost-benefit analysis of publically funded R&D. Hyde et al. (1989), for example, found that the social returns for softwood plywood research significantly exceeded the social costs and that public funding of softwood plywood research was justified on the basis of economic criteria. The social benefits were almost exclusively the result of increased consumer surplus resulting from R&D. Similar justification may not, however, apply in a Canadian context since most Canadian forest products are exported and consumers in other countries are the main beneficiaries of reduced prices.

Contact with Consumers

According to the feedback model of innovation discussed in Chapter 2, close contact with consumers and strong feedback loops between them and producers are distinguishing features of technologically progressive firms. Firms that are successful in developing and introducing new products or differentiating existing products are those with a first-hand understanding of the changing needs, tastes, and preferences of consumers. In addition, firms with new product ideas demonstrate, communicate, and describe the special and unique attributes of their products to customers. A distinguishing feature of knowledge-based industries is strong linkages between producers and consumers.

The Canadian forest industry does not have close contact with the final consumers of its products. An example is the lumber industry, which has a complex distribution network including brokers, wholesalers, re-manufacturers, and retail outlets separating producers from consumers. This distance between consumers and producers inhibits the flow of information between them and limits opportunities for interactions to exchange ideas and develop new product ideas and concepts.

Variability in Product End-use Conditions

In many industries the range of uses of its products are limited and the environmental conditions in which they will be used are relatively constant. Product development and refinement in these industries occur in response to rapid feedback on product performance from testing, experimentation, and use. Researchers can combine this feedback with new scientific and technical information and modify the product or the process to better meet the needs of the users (Rosenberg et al. 1990). Also, since the range of uses and environmental conditions is limited, a stock of broadly applicable information and knowledge develops relatively fast.

Forest products, however, may have a range of applications (for example, softwood lumber is used for framing, beams, roof trusses, etc.) and may be subject to wide-ranging climatic conditions (for example, differences in temperature, humidity, geological stability, extreme weather). Additionally, because of the long life span of wood products, the effects of certain conditions on the performance of particular products in various applications can only be evaluated in the long term. The diverse applications of wood products and their long life spans contribute to a fragmented stock of knowledge that expands slowly over time (Rosenberg et al. 1990).

Production Factors

Abundant Low-Cost Resources

Canada is the world's leading exporter of forest products. One factor contributing to Canada's ability to compete in foreign markets is the abundance of its forests. Abundant timber supply results in a comparative advantage in the production and export of products that require larger amounts of roundwood input per dollar of sales (that is, products that are raw material intensive).

Table 8 shows the amount of roundwood input per thousand dollars of sales for various product types for 1996. Canada's main exports are softwood market pulp and softwood lumber. One of its fastest-growing exports is particleboard. These products need relatively high amounts of roundwood. Newsprint, another major export, requires relatively low amounts of roundwood input, but Canada's share of the world market in this commodity is declining. Thus, abundance of resources has resulted in an industry with a mix of products that are wood-input intensive and that has not had to make significant investments in developing new technology to remain competitive.

Table 8. Roundwood input per thousand dollars of sales for various product types, 1996.

Product type	Roundwood intensity (m^3/\$1000 in sales)
Particleboard	9.5
Fibreboard	8.8
Softwood market pulp	8.8
Hardwood market pulp	7.8
Softwood lumber	6.5
Mechanical pulp	6.0
Kraft paperboards	5.2
Newsprint	4.6
Softwood plywood	4.2
Uncoated papers	4.0–5.0
Coated papers	2.5–2.9

Source: CFS (1996b).

In the future, however, Canada's ability to successfully export wood-input-intensive products will be increasingly challenged by competition from countries with high productivity forests and low labor costs. The Canadian forest products industry also faces increased wood costs and reductions in timber supply and in the availability of higher quality trees. Canadian producers will thus be forced to change their manufacturing philosophy and foster the creation of a knowledge-based forest sector (Binkley 1993). Rather than relying on resource supply and quality as the sole determinant of comparative advantage in the future, Canada will need to combine resource attributes and technology to compete in world markets.

Variability of Raw Materials

Variability of raw materials has an important influence on technological innovation. About 180 native species of trees can be found in the Canadian forest (CCFM 1997). These tree species are distributed over Canada's 11 forested ecozones.[19] The 11 ecozones are classified in terms of climatic conditions, geomorphology, topography, and dominant vegetation. Growing conditions vary significantly across the ecozones; they can also vary within ecozones as a result of differences in local hydrology, disturbance history, aspect, elevation, and other factors that affect tree growth. Differences in growing conditions between sites contributes to variation in fiber characteristics and fiber quality.

Fiber obtained from trees is characterized by its strength, length, color, texture, weight, lignin content, density, specific gravity, tendency to swell, tendency to warp, moisture content, ability to resist decay, chemical composition, and permeability. These characteristics are influenced by and vary according to species, age, region, site conditions, and position of

[19] Forested ecozones are assumed to have at least 15% forest cover. Of the 11 ecozones with 15% forest cover, 8 have 15% productive forest cover.

the fiber within the tree (for example, the properties of heartwood differ from those of sapwood). The infinite number of combinations of these factors results in an extremely heterogenous source of raw material for forest products.

Variability of raw materials has an important influence on technological innovation. It makes it difficult for firms to develop generalized technologies that can be widely applied to all mills owned by a firm; it limits the extent to which scientific information and knowledge are relevant to and useful in the evaluation and analysis of technical problems[20]; and it constrains the rate at which information is accumulated and diffused (Rosenberg et al. 1990)

Although its characteristics are variable, Canadian fiber has properties that provide an advantage to Canadian producers on export markets. However, to date, relatively little attention has been paid to understanding the properties of tree fibers or how forests might be managed to promote favorable properties. Research to assess how management and growth conditions affect productivity and fiber quality, to improve overall understanding of the properties of Canadian fibers, and to develop management techniques that promote favorable and reduce unfavorable characteristics would contribute to creating a knowledge-based forest sector.

Education, Skills, Knowledge, and Experience of the Labor Force

Skilled, qualified, and knowledgeable human resources are necessary for innovation. Baldwin (1997) finds that a lack of skilled personnel is a significant impediment to innovation by Canadian firms. H.A. Simons Ltd. (1991) concludes that a skill shortage in the Canadian forest sector labor force could affect productivity, product quality, the ability to meet customer demands, and product development. Moreover, they find that a significant gap exists between the S&T training needs of workers and the current training capacity of the industry This gap is found at the middle and senior management levels but is particularly pronounced at the operations level. Some of the key findings and recommendations of the Simons study include:

> "There is a significant gap between training requirements and capacity."

> "In Scandinavia, the national co-ordination of industry training is effectively practiced. This type of coordination would likely benefit the Canadian forest products industry and an overall strategy is needed."

> "In today's rapidly changing technological environment, continuing education and training is essential to keep pace with change."

> "Training is critical to achieving effective implementation of technology."

> "Education in the technical transfer process and determining the value of new technologies to competitiveness is critical."

> "There is a substantial gap between continuing education requirements and training opportunities for much of the operational labour force, who in many cases possess less than grade 12 education. Continuing education and training courses are not always available to these workers."

> "Technological awareness is not only necessary at the operations level but must extend throughout an organization."

> "The concept of ongoing education throughout one's entire career is not common thinking within Canada. Most people, once graduated from their program, believe that the education aspect of their life ends, giving way to work and earning income. This way of thinking must change but will continue unless there are clear, measurable incentives for people to seek further education and training."

> "Both industry and government must fund educational and training programs."

Our interviews with forest products technology experts reinforce the Simons findings. A significant number of our respondents indicate that the general lack of highly skilled technical and engineering expertise working on a day-to-day basis at the mill site constrains the innovation process. Skilled and educated graduates have been taken out of the mills

[20] Rosenberg (1990, p. 2) suggests "Technological problems are often too subtle and multivariate for scientific methodology to offer generalized results. The inherent subtlety of the information accounts for many of the difficulties in bringing scientific methodology more effectively to bear upon technological problems."

and placed in research centres.[21] The shortage of technical skills within mills may leave firms less well positioned to network and communicate with equipment manufacturers and suppliers and to serve as technological gatekeepers for firms.[22] It may also reduce the capacity of mill operators to develop technology incrementally (a vital element in an environment with wide-ranging operating conditions and fiber input characteristics). Motivating highly skilled technical people to relocate to rural areas and creating working conditions for them that are stimulating and allow for networking with other technical experts are other challenges facing the forest products sector.

Industrial Organization Factors

Industrial organization is concerned with the relationship between the structure of an industry and the behavior and performance of its firms. The industrial organization of a sector significantly affects its technological capacity. This section looks at some of the structural features of the Canadian forest products sector and evaluates their influence on technological innovation.

Location

Natural resource processing facilities in rural areas often dominate the local economy. Governments often subsidize inefficient mills to maintain local employment. This encourages overcapacity, depresses prices, and penalizes those producers who are efficient (FSAC 1992). Government actions to support economic development in rural areas may be justified on the basis of distribution objectives. However, they may also contribute to industry and community decline if the net effect is to discourage investment in technology development and the adoption of new technology.

Size of Establishments

Table 9 provides an overview of the Canadian forest products industry in 1980 and 1995. The average value of shipments (in constant 1995 dollars) per establishment increased between 1980 and 1995 in all segments of the industry. This trend suggests the possible existence of economies of scale[23] within forest products technologies introduced or adopted between 1980 and 1995.

Table 10 summarizes fiscal year 1994–1995 capacity figures (in thousands of tonnes) for the pulp and paper industry for major producing countries. These data show that Canadian pulp and paper mills are relatively large by world standards, especially in the pulp segment of the industry. Similarly, Canadian lumber mills are also large by international standards (Table 11). For example, in 1995, the 10 largest Canadian lumber companies averaged 261 000 m^3 per mill. In comparison, the 10 largest U.S. companies averaged 178 000 m^3 per mill. The ability of Canadian firms to capture scale economies may have contributed positively to industry competitiveness between 1980 and 1995. In addition, the ability to construct large plants in Canada may be a positive factor relative to the innovation environment for forest products technology in Canada.

Size of Firms

Although the average mill size in Canada is comparable and in some cases larger than in competitor countries, the average firm size is relatively small by international standards. Fifty-six firms worldwide produced more than one million tonnes of paper and board in 1994.[24] Only six of these firms were Canadian-owned. Moreover, the highest ranking Canadian firm was 19th on the list. The average volume produced by these 56 companies was 2.5 million tonnes and by the six Canadian companies 1.8 million tonnes.

Most of the world's major forest products firms are integrated and have diverse product mixes,

[21] The announcement by MacMillan Bloedel to close its research facilities in Burnaby, British Columbia, and move its technical staff to its mills indicates that this firm recognizes the problem.

[22] Recent research into the process of R&D indicates that the pace of discovery and innovation is so rapid and complex in the emerging knowledge-based society that networking and constant feedback are essential for successful innovation.

[23] The concept of "economies of scale" is complex; however, it means generally that in the long term, average unit costs decrease as plant output increases.

[24] The source of this information is Pulp and Paper International, a division of Miller Freeman Inc., 123a Chaussée de Charleroi, Box 5, B-1060 Brussels, Belgium.

Table 9. Canada's forest sector by industry, 1980–1995.

Industry type	1980[a]	1995	1995 Share by industry
Saw and planing mills			
Establishments (no.)	1 317	894	24.3
Employees (no.)	66 278	63 476	28.7
Shipments (Can$, millions)	9 184	14 133	24.6
Value added (Can$, millions)	3 634	5 981	24.4
Shipments/establishment	7	16	
Shingles and shakes			
Establishments (no.)	124	60	1.6
Employees (no.)	2 034	1 765	0.8
Shipments (Can$, millions)	264	240	0.4
Value added (Can$, millions)[b]	115	82	0.3
Shipments/establishment	2	4	
Veneer and plywood			
Establishments (no.)	84	80	2.2
Employees (no.)	12 363	8 485	3.8
Shipments (Can$, millions)	1 461	1 593	2.8
Value added (Can$, millions)	599	723	3.0
Shipments/establishment	17	20	
Total wood industries[c]			
Establishments (no.)	3 363	2 989	81.1
Employees (no.)	117 307	119 013	53.9
Shipments (Can$, millions)	14 611	21 784	37.9
Value added (Can$, millions)	6 030	9 536	38.9
Shipments/establishment	4	7	
Pulp and paper			
Establishments (no.)	144	168	4.6
Employees (no.)	86 872	67 622	30.6
Shipments (Can$, millions)	18 979	24 571	42.8
Value added (Can$, millions)	9 318	12 049	49.2
Shipments/establishment	132	146	
Other paper products			
Establishments (no.)	620	527	14.3
Employees (no.)	43 438	34 303	15.5
Shipments (Can$ millions)	6 256	11 107	19.3
Value added (Can$, millions)	2 462	2 902	11.9
Shipments/establishment	10	21	
Total paper and allied products			
Establishments (no.)	764	695	18.9
Employees (no.)	130 310	101 925	46.1
Shipments (Can$, millions)	25 235	35 678	62.1
Value added (Can$, millions)	11 780	14 951	61.1
Shipments/establishment	33	51	
Total forest industries (wood and allied products)			
Establishments (no.)	4 127	3 684	100.0
Employees (no.)	247 617	220 938	100.0
Shipments (Can$, millions)	39 844	57 462	100.0
Value added (Can$, millions)	17 810	24 487	100.0

Source: Statistics Canada (1980 and 1995), Cat. no. 25-202-XPB.

[a] Converted to 1995 constant dollars using a GDP-implicit price deflator.

[b] Value added is for total activity. Shipments are for goods of own making.

[c] This category includes the three industries above plus Standard Industrial Classification 254 (slash, doors, and other mill work), SIC 256 (wooden boxes and pallets), SIC 258 (coffins and caskets), and SIC 259 (other wood industries).

Table 10. Capacity of pulp, paper, and board mills in major producing countries, 1994–1995.

	No. of mills		Avg. capacity (000s tonnes)	
Country	Paper and board	Pulp	Paper and board	Pulp
Canada	117	39	169	706
United States	537	190	164	327
Sweden	50	46	193	229
Finland	44	43	270	267
Commonwealth of Independent States	161	50	69	216
Japan	441	49	72	305

Source: Matussek et al. (1996).

ranging from pulp and paper to solid wood to secondary products. Table 12 shows the position of Canadian integrated firms with respect to firms in other countries. Canada has 5 companies in the top 50. The average size (based on average total sales per firm) of Canadian firms ranks 8th out of the 9 countries. Average sales for the 20 U.S. firms in the top 50 list was US$4.8 billion and for Canadian firms about US$1.7 billion. Thus, in terms of firm size, Canada ranks among the lowest of the major forest products producing nations. If economies of scale are important in forest products related R&D, the relatively small size of Canadian forest products firms places them at a disadvantage to firms in other countries in developing a technological capacity.

Industrial Concentration

The Canadian forest products industry is an unconcentrated industry.[25] The lack of concentration may inhibit R&D investment and technology development if technology and knowledge are easily transferable from firm to firm. On the other hand, lack of concentration, with its associated competitive pressures, may stimulate innovation if technology and knowledge are largely specific to the individual firms performing the R&D (or if firms are somehow able to limit or restrict the technology from spilling over some other way). The technology strategies of firms in the Canadian forest sector are consistent

Table 11. Average mill size of top 10 lumber producers in Canada and the United States, 1995.

Name	No. of mills	1995 Production (000s m³)	Avg. annual output per mill (000s m³)
		Top 10 Canadian firms	
Canfor	11	3 417	311
West Fraser	8	3 094	387
Northwood	5	2 473	495
Slocan	8	2 419	302
Weldwood	6	2 303	384
MacMillan Bloedel	10	2 122	212
Buchanan	6	1 888	315
International Forest Products	9	1 782	198
Donahue	12	1 397	116
J.D. Irving	10	1 291	129
Total	**85**	**22 186**	**261**
		Top 10 U.S. firms	
Weyerhaeuser Co.	42	9 893	235
Georgia-Pacific	41	5 735	140
Sierra-Pacific	13	3 245	250
Louisiana-Pacific	32	3 207	100
International Paper	11	2 074	189
Boise Cascade	11	1 683	153
Federal Paper Board	5	1 517	303
Simpson Timber	5	1 484	297
Pope and Talbot	5	1 482	296
WTD Industries	12	1 232	103
Total	**177**	**31 552**	**17**

Source: Pease et al. (1996).

with the latter model. The sector has limited capability in the development of proprietary technologies that can be easily appropriated (such as new products, new processing systems, new machinery and equipment). However, the industry does undertake considerable incremental, site-specific R&D,

[25] The degree of concentration in an industry is measured in a variety of ways. Concentrated industries are characterized by market structures where one or a small group of firms can potentially influence the price of outputs or inputs by their production decisions. No single firm, or small group of firms, in the Canadian forest products industry is in a position to do this; therefore the industry can be considered to be unconcentrated.

Table 12. Average size of firm by country of origin, based on the 50 largest forest products firms in the world, 1994.

Country	No. of firms in the top 50	Total sales 1994 (US$, millions)	Avg. sales per company (US$, millions)
United States	20	95 559	4 778
Japan	7	29 010	4 144
European countries[a]	5	19 997	3 999
Sweden	4	15 504	3 876
Finland	4	15 335	3 834
Germany	1	2 748	2 748
Australia / New Zealand	3	7 391	2 464
Canada	5	8 711	1 742
South Africa	1	1 668	1 668
Total	**50**	**195 923**	**3 918**

Source: Price Waterhouse (1995).

[a] Not including Sweden, Finland, and Germany.

which is not easily transferable between establishments. The low level of concentration of the industry is a contributing factor to this pattern of innovation.

Entry and Exit Barriers

Relatively high levels of industrial concentration may be a misleading indicator of producer market power if entry into an industry is relatively easy. Since difficulties in exiting an industry will be factored into decisions made to enter an industry, overall barriers to new competition consist of both entry and exit costs. Ease of entry and exit is largely conditioned by the sunk cost investments required to participate in a market. Sunk costs are costs that cannot be recovered if the firm ceases to engage in the relevant set of activities. They are typically associated with investments in assets that are idiosyncratic or specialized to the activities in question. Idiosyncratic capital investment requirements are not likely to be a substantial barrier to entry into the Canadian forest sector, especially in the wood industries sector where capital requirements are much more modest than in the pulp and paper industry. A more relevant issue is access to timber.

In countries such as Canada, where the majority of forests are publically owned and where timber cutting rights are allocated by the government, it is not so much sunk costs (or idiosyncratic capital costs) as government forestry policy that conditions ease of entry. Specifically, firms may be restricted in terms of entry or expansion because of direct limitations on the allowable cut on Crown land.

Indirectly, therefore, perceptions by governments about the optimal rate of harvesting represent important exogenous influences on entry conditions in the forest industry. These perceptions take into account competing public uses for the forest, environmental concerns, and rates of depletion of timber stands. Environmental policies are also an important influence on entry and expansion decisions in the industry. In particular, requirements to reduce and/or restrict pollution from pulp and paper mills add an additional cost (often significant) to the (largely sunk) capital cost requirements of this sector. Since it is often less expensive to build clean technologies in new pulp and paper mills than to modify polluting technologies in older mills, public sector environmental policies can affect exit as well as entry decisions.

Ease of entry and exit can sway innovation activity to the extent that they influence competitive conditions in an industry. Broad empirical evidence suggests that a moderately concentrated industry with relatively low barriers to entry and exit may be the market structure most conducive to rapid rates of innovation. As discussed, however, the forest industry is not concentrated and the barriers to entry are significant.

Horizontal and Vertical Integration

The extent of horizontal and vertical integration within an industry affects the degree to which firms can "internalize" technological changes. The higher the level of integration of a firm, the more broadly it can apply technological changes. The more broadly applicable a new technology is, the more motivation a firm has to invest in R&D.

Vertical integration is a ubiquitous feature of the North American forest products industry. Unfortunately, summarizing the nature and extent of vertical integration is not easy, since different firms are integrated through different stages. Major producers of pulp and paper products are frequently integrated backward[26] to include the logging activity. Conversely, major logging firms are less likely to be integrated through to the production of pulp and paper products (Cohen and Sinclair 1991). In the 1960s and 1970s, forest products firms integrated forward into distribution. Controlling distribution channels supposedly brought a firm closer to the end-user and sensitized management to changing consumer needs. In the 1980s, recessionary conditions forced firms to focus on core production competencies (Cohen and Sinclair 1991), rather than ownership of distribution channels. This illustrates how economic conditions and markets can lead firms to adopt strategies that discourage their development and/or innovation of new technology.

Canada's relatively small domestic market inhibits the establishment and growth of the forestry equipment manufacturing industry. Some experts interviewed for our study felt this limited innovation in the forest products sector because proximity to equipment manufacturers encourages joint ventures in developing new technologies and products and in adapting technologies to local conditions.[27] Respondents could offer no clear suggestions on how to overcome the problem of the small domestic market. Some referred to government policies in Scandinavia that encouraged the growth of an equipment manufacturing capacity; however, they also cautioned against government intervention and subsidies to establish a similar capacity in Canada. Mention was made of the Province of Quebec's significant effort to develop a supporting forestry equipment manufacturing industry through R&D tax credits and infrastructure grants.

[26] Backward integration means that a firm in a particular industry moves into industry sectors that supply it with materials, goods, or services. Forward integration means that a firm in a particular industry diversifies into industry sectors that purchase and use its products.

[27] Empirical evidence documenting the importance to innovation of close linkages between equipment manufacturers and equipment users is found in von Hippel (1978). Hayter (1987) cites the close linkages between forest products companies and equipment manufacturers in Scandinavia as an important reason for the latter's observed innovation success.

Institutional Factors[28]

Environmental Values

Current public values and attitudes have resulted in the forest sector making significant changes in forest management, harvesting practices, and production processes. Some of these changes have resulted in redirection of R&D resources away from the development of commercial technologies to the development of environmental technologies (FSAC 1992).

Intellectual Property Rights Protection

The patent system encourages private sector investment in technology development. However, patenting also discourages the broader dissemination of knowledge to society. A considerable volume of literature exists on the issue of optimal patent systems and the differences between industries in using patents to prevent imitation. Levin et al. (1987) suggest that the use of patents to protect against imitation is only one (and often the least common) strategy for appropriating the benefits of new technologies. Other strategies include superior sales and service capability, an R&D lead, and the capacity to move up the learning curve faster than other firms.

The forest industry experts interviewed for our study did not believe that a stronger patent system was required in Canada to encourage a higher level of private sector participation in commercial technology development in the forest sector.

R&D Tax Credits

The Scientific Research and Experimental Development (SRED) tax credit provides about $1 billion per year in incentives for private sector R&D. Because the tax credit is refundable, taxable income is not required to take advantage of the incentive.[29] Canada's R&D tax credit system is competitive with such systems in other countries and is far superior to most in terms of its generosity (McFetridge 1995). SRED provides fully refundable tax credits on the first $2 million in R&D expenditures for all firms with less than $200 000 in taxable income. Tax credits are partially refundable for firms with taxable incomes between $200 000 and $400 000. Firms with taxable incomes in excess of $400 000 are not eligible for the tax credit. Some provinces, notably Nova Scotia, Ontario, and Quebec, provide additional R&D incentives through their provincial tax systems.

Are tax-based incentives as effective as grants and subsidies in stimulating R&D in the private sector? Is the cost–benefit ratio higher for one dollar of R&D incentive if it is delivered by the tax system or through grants and contributions? This complex issue is beyond the scope of this report, but does merit further analysis relative to the development of policy and program alternatives for stimulating a higher level of private sector participation in R&D in the forest sector.[30]

S&T Policy, Programs, and Agencies

Appendix 2 outlines a number of specific federal programs with goals to conduct or facilitate R&D and/or improve, enhance, and/or motivate R&D and innovation in the economy. There is often, however, an institutional bias towards the high technology sectors (for example, aerospace, telecommunications, information technologies) in public policy. In addition, technology's role in and significance to the future competitiveness of natural resource sectors such as the forest products sector are not recognized in public policy. It is important that there be inherent strategic opportunities for developing market niches in the global economy by combining technology with Canada's rich natural resource base.

[28] North (1994) describes institutions as follows: "Institutions are the humanly devised constraints that structure human interaction. They are made up of formal constraints (e.g. rules, laws, constitutions), informal constraints (e.g. norms of behaviour, conventions, self-imposed codes of conduct), and their enforcement characteristics. Together they define the incentive structure of societies and specifically economies." He goes on to suggest "If institutions are the rules of the game, organizations and their entrepreneurs are the players."

[29] This feature of the tax credit system should help industry bridge periods of low profitability and provide greater continuity in R&D funding commitments.

[30] Another issue is the extent to which the tax credit system discriminates between large and small firms and the extent to which differences in treatment of large and small firms is justified given broader trends in the global economy (e.g. the trend towards increasing firm size, the growing importance of technology in global markets).

Cooperative Research Institutes

The importance of cooperative research institutes[31] to the innovation process in the Canadian forest products sector has grown since the early 1980s and is expected to rise in the future. Kumar and Magun (1995) describe the reasons for growth of technology consortia as follows:

> The apparent reasons for the growth of technology consortia in the United States, Canada and other major industrialized nations are related to the leveraging of scientific and engineering expertise and of financial resources and the pooling of risks attached to undertaking R & D at the technological frontier. In fact, the factors driving the formation of technology consortia are deeper, more subtle and more permanent. The three forces influencing technology consortia in the global marketplace are globalization of the world economy, technology trends and industrial policy that advocates a greater role of government in shaping a country's comparative advantage. These forces are not mutually exclusive but often overlap and reinforce each other. From a technology perspective, they have engendered two contradictory phenomena. They have encouraged the establishment of cross-border technology collaborations but at the same time they have made major trading nations more protectionist about their technology based competitive advantage.

There are three cooperative research institutes that undertake R&D in the forest products sector: Paprican, Forintek, and FERIC.[32] Historically, research partnerships have provided a popular and effective mechanism for sharing the costs and risks of R&D in the forest sector. The types of research undertaken or facilitated by these partnerships are open-science research with commercial potential, infra-technology development, pre-commercial R&D, product development, and environmentally oriented R&D. Partnership allows more efficient use of scarce R&D resources and enhances the innovation process by improving feedback between open-science research and the private sector. Cooperative research institutes are also involved in technology transfer, product testing, and the development of product standards.[33]

The industry respondents to our survey indicate that pre-commercial research by cooperatives provides a useful platform from which industry can develop commercial innovations. They are concerned about the research findings of these cooperatives leaking out or spilling over to firms outside of Canada, possibly from Canadian affiliates of foreign-owned firms. Because the cooperatives focus mainly on researching methods to exploit the unique characteristics of Canadian fiber, the respondents feel that the magnitude of this leakage is limited.

Continued structural changes in the global economy will increase the need for and enhance the role of cooperative research institutes. However, partnerships by their fundamental nature cannot fully substitute for in-house research capacity. Private sector investment by individual firms seeking profits will continue to be necessary for the development of commercial technologies. In-house research also allows a firm to make continual small improvements in production methods and product quality. Such capability is important given the great variability in the characteristics of Canadian fiber inputs. Finally, a capacity for in-house research provides the necessary expertise within the firm to monitor new technological developments and evaluate and make recommendations regarding their applicability at a local level.

Canadian firms may be limited by their small size in the development of a critical mass of competitive research capability compared with firms in other countries. Strategic alliances of small firms to perform joint research ventures provide one mechanism for obtaining scale economies and dealing with the problem of small size. Few alliances of this type exist within the Canadian forest products industry. They are more common in other countries;

[31] The institutional framework provides the rules and conditions for conduct and performance among and between organizations. This section focuses on institutions and their role in facilitating and directing the technological innovation activity in the forest products sector. An overview of the various organizations involved in science and technology in the forest sector is provided in Appendix 2.

[32] Appendix 2 provides additional information on the cooperative research institutes.

[33] Cooperative forest products research institutes also exist in Sweden, Finland, New Zealand, Chile, Japan, and the United States. The United States also has fully government-funded forest products research laboratories.

for example, in Japan the government provides direct support and incentives to small and medium-sized firms that undertake joint research proposals (Kumar and Magun 1995; Nakamura et al. 1997).

Public Policies

The incentive structure for technological innovation (and ultimately the technological capacity of firms) is sensitive to, and can be affected indirectly (and unintentionally) by, a broad range of policies and regulations. For example, subsidization of inefficient mills may result in depressed prices and reduced incentives to develop and/or invest in new technology by successful firms with the capability to make such investments. Stumpage pricing regimes that do not differentiate between resource rents and monopoly profits attributable to innovation can reduce or eliminate the incentive for innovation. Perceived insecurity in timber supply is a deterrent to the development and/or enhancement of technological capacity.

Enhancing the technological capacity of the forest products industry is important in meeting the demands of a changing global economy. In this light, decision makers must consider the full range of impacts that policies, programs, and regulations have on the technological capacity of firms and on the incentive structure for investing in technology development and application.

Redefining the Role of Technology in the Canadian Forest Products Industry

Where there is much desire to learn, there of necessity will be much arguing, much writing, many opinions; for opinion in good men is but knowledge in the making.

John Milton

In this chapter we examine the changing competitive circumstances of the Canadian forest products industry and how these changing conditions are expected to circumscribe the future technological requirements of the forest industry. We also review and summarize the findings from previous chapters and reorganize them into issues and considerations for positioning the forest sector in a knowledge-based global market.

Competitive Challenges and Opportunities for the Industry

Growth in global population and in per-capita incomes is expected to result in increased global demand for the major commodity forest product groups. The FAO forecasts an annual rate of growth in demand of 3.8% in paper products, 2.7% in wood products, and 2.7% in roundwood over the period 1993–2010 (FAO 1995). However, these increases in demand will not be evenly distributed. The North American market (which is the market of greatest importance to Canadian producers) for forest products is more mature than markets in the newly emerging economies, and growth in demand will be more modest. Growth in demand is expected to decline for plywood, to be moderate for softwood lumber and newsprint, and to increase significantly for engineered wood products, medium-density fiberboard, particleboards, and oriented strandboards.

In the long-term, the economies of Asia-Pacific countries are expected to outperform those of other regions of the world. The emerging economies in the Pacific Rim will likely provide some market development opportunities for the Canadian forest products industry. The overall demand for building materials and pulp and paper products will probably exceed the domestic supply capacity of Pacific Rim countries, creating export opportunities for foreign suppliers. However, competition in commodities such as market pulp, newsprint, and softwood lumber, Canada's prime export products, will be strong from producers in Indonesia, Malaysia, New Zealand, Chile, Brazil, and Russia. One way for Canadian producers to respond to increased competition is to provide differentiated and superior commodity products and value-added products at low cost to consumers in North America and Asia. This approach, however, will require that the industry improve its technological capacity.

Global trade is affected by multilateral trade rules. In 1994, the most recent round of multilateral trade negotiations, known as the Uruguay round, was concluded. The agreement, administered by the World Trade Organization, was signed by 125 countries and took seven years to complete. The agreement includes widespread reductions in tariffs, a number of which pertain to forest products. For example, as of January 1999, tariffs on pulp and paper products were eliminated across all industrialized countries and those on wood products were reduced. On low value-added commodities such as pulp and lumber, tariffs are declining rapidly; however, on higher value-added products, the reductions in tariffs are less significant. Tariffs on downstream processing sectors in many countries tend to be high and the countries less willing to support significant tariff reductions.

Non-tariff barriers also affect trade. Some examples of non-tariff barriers affecting forest products are U.S. newsprint recycling requirements, phytosanitary and plant heath regulations, building codes and standards, environmental standards, eco-labels (stating that production of a particular product has not resulted in unacceptable environmental degradation), conventions (for example, CITES, the Convention on International Trade in Endangered Species), and product quality assurance standards. Historically, market access depended on providing quality products at competitive prices. In the future, it may depend on fast delivery of competitively priced and consistent-quality products that meet local consumer standards in terms of quality assurance and environmental performance. These new demands affect the future technological requirements of the industry. For example, the growing importance of non-tariff barriers suggests the need for a stronger emphasis on infra-technology development.[34]

Canadian solid-wood building products face competition in traditional materials from suppliers in the United States, Sweden, and Finland, and increasingly from newly emerging suppliers. In addition, Canadian producers are facing increased competition from producers of non-wood building materials such as steel, aluminum, and plastics. Increasing the knowledge content of Canadian wood-based products could improve overall production efficiency and product quality.

Canada's traditional competitors, the United States, Finland, and Sweden, have a considerable lead in enhancing their technological capacity. Also, forest industry developments in the European Union have allowed Europe to be more than self-sufficient in supplying their lumber and newsprint needs and about 85% self-sufficient in meeting demand for pulp. European producers are already aggressively positioning products in both the U.S. and Japanese markets, thereby creating new competition for Canadian firms.

The technological lead of U.S. and Nordic producers may be offset, to some degree, by other competitive disadvantages. For example, the timber supply from public lands in the U.S. Pacific Northwest has been reduced by about 90% over the last 10 years because of measures to protect the spotted owl and old growth forests. Nordic producers pay more for energy and transportation to the United States than Canadian producers do. However, in the long term, Canadian firms may not be in a position to effectively compete with Scandinavian and U.S. firms without making some effort to close the technology gap.

Canada's share of global trade in forest products declined from 22% in the 10-year period 1965–1974 to 20% in the period 1985–1994. At the same time, non-traditional suppliers—Chile, New Zealand, Spain, Portugal, Brazil, Malaysia, and Indonesia—increased their share of global trade from 6% in 1965–1974 to 13% in 1985–1994 (CFS 1996b).[35] The comparative advantages of these newly emerging suppliers include large areas of natural forests, high-productivity plantation sites, significant areas of plantations that are approaching maturity, and lower labor costs. Another important factor is the availability of new technologies that have diminished the grade differences between products produced from northern forests and those produced from fast-growing eucalyptus and radiata pine plantations.

The impact of economic and institutional reforms in the former Soviet Union is largely unknown but it has potentially major consequences for the Canadian forest products industry. The former Soviet Union has about 55% of total global softwood stocks and is a major potential supplier of relatively low-cost softwood fiber. Major obstacles to the emergence of this region as a significant supplier include the geographic dispersion of its forests, the expense of effective reforestation efforts, and a limited transportation capacity (Stanbury et al. 1991). Nevertheless, once the institutional barriers and constraints on investment in Russia decrease, the capacity of the Russian forest products industry will grow. Backman and Zausaev (1998) suggest that although current roundwood exports are modest (5 million m^3/year), in 25 years exports to the Pacific Rim are expected to more than triple to reach a level of 19 million m^3/year.

In the past, the Canadian forest products industry modernized and improved its technological base by expanding into new and undeveloped forest areas. In some cases, expansion was achieved by constructing new mills using the most recent technology and fully exploiting the economies of scale associated with a particular modern technology. In other cases, expansion was realized by upgrading and expanding an existing facility; this often provided the opportunity to install state-of-the art machinery and equipment. However, expansion opportunities

[34] A stronger emphasis on infra-technology development is important because market access may depend on the stock of knowledge on product characteristics and performance under a range of environmental conditions.

[35] The recent devaluations of the Asian currencies (for example, the rupiah in Indonesia) would make their products even more competitive.

into undeveloped areas are declining. Consequently technological upgrading of the Canadian capital stock through expansion will decline.

Sustainable development has been largely adopted as a policy goal by provincial and federal forest agencies. This affects policies, management goals, and monitoring and assessment approaches and processes. Management goals have evolved from a timber management perspective, which focused on objectives such as forest regulation, to a forest ecosystem management perspective, which embodies a broader range of goals and requirements such as conservation of biological diversity, maintenance of the productive capacity of ecosystems, maintenance of forest ecosystem health and vitality, and conservation and maintenance of soil and water resources.

An improved scientific understanding of forest dynamics, ecosystem processes, and biodiversity benefits the forest industry in a number of different ways. First, without an informed understanding of how ecosystems function and what kinds of harvesting systems will be most effective in maintaining ecosystem processes, policy and management guidelines may fail to achieve sustainable management. Second, the way forests are managed has direct implications for fiber characteristics. Third, the globalization of environmental issues has direct market implications. Increasingly, consumers in external markets will demand assurances that their consumption activities are not resulting in degradation of Canada's forests (Stanbury et al. 1995).

Issues, Options, and Challenges

Binkley (1993) argues that the transformation of the Canadian forest industry from a resource-based to a knowledge-based sector is an economic, social, and political necessity. The Canadian Council of Forest Ministers' *National Forest Science and Technology Course of Action* (CCFM 1998) reinforces this message. Numerous analysts have argued for significant improvements in the technological innovation performance of the forest products industry and for enhanced commitments to R&D (for example, Hayter 1987, FSAC 1992, CCFM 1988). In this report we do not take issue with these findings and opinions, nor do we endorse them. However, there are a number of issues, options, and challenges that should be considered if transformation of the forest industry to a knowledge-based sector is going to be achieved. In the remainder of this section we present an overview of these considerations.

Knowledge Content

Declining competitiveness, reduced employment, lower incomes, unstable communities, reduced investment, non-compliance with management and environmental regulations, unsustainable forest practices, declining market shares, declining investment, lower taxes, and lower stumpage payments are potential future consequences of a situation where the forest industry fails to increase the knowledge content of its products and processes. Given the structural and institutional barriers described farther on, it is unlikely that there will be any change in performance without some kind of targeted action or effort. The level and design of this effort will depend on an assessment of trades-offs between the costs and benefits of action versus those of inaction as well as an evaluation of the strategic and social importance of maintaining a strong and competitive forest sector.

Recognition of Common Concepts

Any discussion and analysis of future directions pertaining to technology in the forest industry must be grounded in a common understanding of the properties of knowledge and the process of innovation. The linear model of innovation is based on an understanding that innovation is a one-way flow of information and knowledge from basic research through to applied research to commercialization. Although some in the forest sector still hold to this model, most have embraced the feedback model of innovation (see Chapter 2). In the rapidly changing global and information economy the linear model of knowledge creation and innovation will not adequately inform policy- and decision making.

A new contextual basis for discussing, assessing, and managing technology in society and a broad recognition for it are required. The current work of the Canadian Institute of Advanced Research (CIAR) and other research can be of assistance in articulating such a contextual basis. For example, the CIAR describes the emergence of a new techno-economic paradigm that explains the process of and the role of various players in innovation. Efforts should be made to describe this new approach and modify it as necessary for the purpose of developing a better understanding of innovation processes in the forest sector and how institutional design influences these processes.

Inherent Bias to "High Tech"

Many people feel that resource industries are "low" technology and that the future of the Canadian economy rests on restructuring from a resource-based to a high technology, manufacturing-based economy. This inherent bias translates into a bias towards the high technology sector in S&T policy and programs. Decision makers need to understand better the important role of technology in resource sectors, the consequences of not enhancing technological performance, and the opportunities arising from the integration of knowledge and technological capacity with existing strengths in the resource areas. At the same time, the resource sectors need to appreciate that S&T resources must be allocated objectively and to those areas and initiatives that provide the largest net social benefits or are the most cost-effective in achieving distributional objectives.

Adequacy of R&D Funding

R&D is only one of many inputs to innovation. Other important elements include effectiveness of technology transfer, existing stock of knowledge (including tacit knowledge), receptiveness of firms, labor force skills, feedback mechanisms, institutional effectiveness, and linkages to suppliers and customers. Technology strategies for firms and the Canadian forest sector in general should consider all of these elements. Although this discussion focuses on R&D funding levels, we should remember that R&D is only one of a number of important inputs to the innovation process.

The intensity of R&D expenditure by the Canadian forest industry and federal and provincial governments is low compared with other countries. Increased investment in R&D by firms and governments may be necessary to improve the knowledge intensity of Canada's forest products. However, the decision to increase funding levels of R&D by firms and governments needs to be based on confidence in the productivity and efficiency of the R&D establishment to encourage innovation, the expectation of reasonable returns on investment, and/or an ability to achieve some strategic goal or social objective. Recent economic analyses suggest that the private and social returns on investment in forest products R&D are positive but relatively low. However, as discussed in Chapter 3, these studies have an inherent bias towards underestimating the returns on investment. Moreover, they are based on the return on historical investment and not on the potential return on current investment.

Countervailing Policies and Regulations

Some environmental, social, and resource management policies may have a negative impact on the incentive of firms to upgrade capital by investing in production technology and product development. For example, stringent environmental regulations cause firms to direct their R&D efforts into developing environmental instead of commercial technologies. Stumpage pricing policies and tenure obligations are another example of how policy can affect technological capacity. The failure to differentiate technology rents from resource rents may result in provinces absorbing technology rents, thereby reducing the incentive to invest in technology development. Success of the efforts to maintain and/or enhance the technological capacity of the forest industry will depend on governments recognizing, understanding, and accounting for the impacts that policies and regulations have on the capacity and/or willingness of firms to develop technology and innovate. Assessment(s) of the impact of social, environmental, and resource policies on the technological capacity of firms as a criterion in policy evaluation may help to avoid the implementation of policies that have indirect or unaccounted for effects on technological capacity.

Structural Barriers

Chapter 4 provided an overview of a number of structural barriers that constrain innovation. Some examples are cyclical markets, inelastic demand, small size of firms compared with other countries, and poorly developed communications networks between producers, customers, and equipment suppliers. These barriers stifle innovation and are difficult to counteract. Some ways to overcome these barriers include differentiation of products (to escape the commodity cycle), promotion and encouragement of strategic R&D alliances between two or three firms, promotion and encouragement of mergers and acquisitions, and development of mechanisms to provide greater continuity in funding. An example of the last option would be to establish R&D endowments to provide stable funding for research cooperatives at the firm, strategic alliance, or higher level.

Role of Governments

Some experts argue that R&D should receive higher priority in public policy. This view gives rise to a number of questions. What role should government play with respect to encouraging and enhancing the development and innovation of commercial technology? What level of public funding should be devoted to open science, to pre-commercial technology development, and to commercial technology development? What types of instruments would be most effective for achieving science and technology objectives in the forest sector? Is there a need for a more flexible approach, which allows the tailoring of a mix of science and technology policies and programs to various sectors? What is the interrelationship and/or degree of compatibility between S&T policies and objectives and other policies and objectives (for example, natural resource policies, human resource policies, taxation, trade policy, investment policy, industry policy, economic development)? These are important public policy questions that will require more discussion, consultation, review, and analysis.

In some cases, public interventions attempting to encourage technology development may not be desirable because of "government failure." Government failure occurs when governments cannot or do not intervene to satisfactorily correct for market distortions and market failures or when the costs of interventions exceed the social benefits. To avoid this, governments must ensure that the capacity and skills for the effective design, delivery, and evaluation of public sector S&T policies and programs are in place. A combination of public and private sector skills, funding, and management systems through partnerships may provide the most effective model for enhancing technology. There is growing recognition of the importance of feedback, networking, and partnerships in guiding and managing the S&T interface. Public agencies must actively participate in this feedback process. Furthermore, public agencies must be prepared to adapt and respond to signals provided through feedback processes while at the same time acknowledging the need for long-term commitments.

The boundary between forest resource management practices and competitiveness is blurring. There are two dimensions to this growing. First, the general trend towards "greening of markets" means that to ensure continued access to markets, management agencies (and firms) must demonstrate that forests are managed sustainably and scientifically and that harvesting is not leading to irreversible losses of ecological attributes. Second, forest management practices affect the rate of growth of forests as well as the inherent characteristics of the fiber produced and thus condition the range of options that firms have in developing new products. Forestry R&D can help to develop a better understanding of the relationship between forest management practices and forest fiber quality and to identify how forest management might be used as a tool to create or reinforce favorable fiber characteristics. Thus, although the responsibility for forest-oriented R&D rests with governments, the forest industry, resource managers, and forest researchers need to communicate more effectively to ensure that R&D efforts provide maximum benefits to Canadian society.

An analysis of optimal ways to design and deliver public sector R&D policies and programs should be conducted. In particular, identification of institutional arrangements that provide accountability and are responsive to changing circumstances should receive high priority. The effectiveness of various mechanisms (for example, grants, loans, tax expenditures, contingent levies, infrastructure grants, stumpage relief, and in-house research) should be studied. Such assessments should also examine new institutional arrangements within the public and private sectors and the feedback linkages between them.

Role of Research Cooperatives

Cooperative research institutes are providing the forest products sector with strategically important knowledge and technology to deal with generic, industry-wide, pre-commercial technology issues. Research cooperatives also serve as technology gatekeepers through their network of forest products research institutes in foreign countries. A certain amount of spillover of Canadian technologies from these organizations is inevitable, but is compensated for by their role in enhancing the diffusion of technologies in Canada and increasing Canada's ability to benefit from technology developed in other countries.[36]

The industry-wide cooperative research institutes facilitate interaction between open- science, pre-commercial research, and commercial research efforts. These institutes would need to play a key role in any national strategy to promote the technological capacity of the forest products sector. However, the extent to which individual firms derive benefits from these cooperatives is in part a function of their own technological capabilities. Firms with higher technological capabilities are likely to benefit more from and be in a position to apply pre-commercial technologies and knowledge developed by cooperative research organizations. Thus, the promotion of "in-house" capabilities by firms (or groups of small firms) is important for increasing the rate of use of technology and knowledge developed by research cooperatives.

Role of Universities

Universities contribute to knowledge creation and ultimately to innovation processes. They perform research; supply skilled professionals to the marketplace; and contribute to the management, coordination, and promotion of science and technology by offering time and expertise to advisory bodies, coordination mechanisms, and policy task forces. One of the findings of contemporary models of innovation is recognition of a growing linkage between science and technology. Product and process development are becoming more and more sophisticated and science-oriented. Scientific discovery is being translated into commercial application, and commercial requirements are increasingly having an influence on the orientation and direction of scientific research.The relationship between universities and industry is strengthening.

Complementarities within the R&D Establishment

R&D performers include private sector firms, cooperative research organizations, universities, government research agencies, and machinery and equipment developers and suppliers. The knowledge generated by these various performers complements and contributes to the overall spectrum of knowledge requirements in the forest sector. The contributions of one performer can not necessarily substitute for those of another. The challenge is to ensure that these various performers are linked, that R&D is coordinated, and that the cumulative impact relative to the stock of useable knowledge is maximized.

Diversity of Firms

Every firm has unique characteristics and will have unique goals, strategies, and capacities relative to production efficiency, management, marketing, technological innovation, and investment intentions. Diversity of firms implies that firms have different needs and capabilities and any strategies to enhance performance will need to take this diversity into account.

Canadian Fiber Resources

The characteristics of fiber inputs can affect final product quality. However, fiber characteristics vary widely depending on species, region, rate of growth, local growing conditions, position of fiber within the tree, and management practices used to produce the fiber. Understanding how to control fiber characteristics through management techniques is complex, but essential for developing

[36] Note that governments in some countries forbid membership of foreign companies in domestic research cooperatives that receive government funding. The purpose is to prevent government-funded research outputs from spilling over and benefiting producers and consumers in foreign countries. Canada is less aggressive in this area.

efficient conversion technologies and products that consistently exhibit desirable and saleable features. However, the level of research effort devoted to analyzing the characteristics of fiber in Canadian forest resources and to understanding how management methods affect them is relatively low. This area may require more attention if the Canadian forest sector is to be successful in developing and implementing an effective competitiveness strategy based on technological innovation.

Technology Spillovers

To limit technological spillover to foreign firms, public support for pre-commercial and commercial R&D should focus on technologies geared to processes and products that exploit the unique features and characteristics of the Canadian forest resource. Similarly, some level of effort should be made to appropriate, where possible, technologies developed in foreign countries.

The Workforce

The availability of skilled, qualified, and knowledgeable human resources is a necessary condition for innovation. Studies of the forest industry workforce have concluded that there is a skill shortage in the labor force that could potentially affect productivity, product quality, and the receptiveness of firms to technological change. Additionally, a significant gap exists between the scientific and technical training needs of the workforce and the current training capacity. Improvement in the technological performance of the industry is unlikely to occur without major improvements in the skill levels of the forestry workforce. Expanded education and training programs are required and they should be funded by both industry and government. Priority should be given to upgrading the skills of workers in the operations area of the sector; however, engineers, technicians, and middle and senior managers also require training.

Consumer Contact

Product differentiation would reduce the vulnerability of Canadian producers to expected increased competition from low cost producers in traditional commodity markets; also, it would disengage Canadian firms from cyclical commodity markets. However, product differentiation must involve not only technological progress but also a significant marketing effort. Strong feedback between consumers, producers, and researchers is an important aspect of this issue.

Strategic Vision

The U.S. forest products sector has developed and is implementing a technology vision statement to guide the sector into the next millennium. The Canadian forest products sector could benefit from the establishment of a similar type of statement, one that encourages cooperation and coordination and provides some recognition of the importance of technology to the future competitiveness of the forest industry.

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Organizations Involved in Forestry and Forest Products R&D in Canada

In this appendix we provide an overview of the science and technology (S&T) system. We do not consider the structure of the forest sector S&T system, the interconnections between the various players, the effectiveness of the S&T system in contributing to technological change and competitiveness, and the relationship of the S&T system to its external environment (that is, the effect of tax policies, trade policies, resource policies, and industry policies on the level of S&T and the effectiveness of the system). Some information on these factors is provided in Chapter 4.

Table A2.1 is a schematic perspective of the main elements of the forest sector S&T system. It includes examples of firms, agencies, organizations, and/or programs that directly or indirectly affect or influence the rate of invention and discovery, the rate of innovation of the Canadian forest products sector, and the development and use of technology in support of improved forest management policies and practices.

Private Sector Firms

The function and role of technology experts in private sector firms is not restricted to R&D activities geared to the development of new products and processing technologies.

Technology experts serve a broad range of functions that contribute to an ongoing process of innovation and improvement for firms. These functions include serving as technological gatekeepers; contributing to, monitoring, and applying research results provided by collaborative research organizations or external research agencies; providing information, advice, and assessments to plant managers and executives; troubleshooting; developing new proprietary products and processes; and testing, modifying, and refining new prototype technologies and/or existing processing systems.

The process of technology development and acquisition and technological change is managed in a number of different ways by forestry companies in Canada. In some cases, firms support significant internal R&D capacity in centralized facilities. The knowledge and technologies developed by these organizations are diverse but tend to be concrete, measurable, and codifiable. Examples of firms that undertake significant levels of in-house R&D are Canfor (at the Canfor R&D Centre, Vancouver), Domtar (at its Innovation Centre in Senneville, Quebec), and Noranda (at the Noranda Technology Centre in Pointe Claire, Quebec). These firms are among Canada's most technologically progressive companies and make significant investments in R&D; they focus on improving existing processes and products, developing new value-added products and more efficient production processes, and protecting the environment. Their research facilities generally include some combination of offices, laboratories, pilot plants, technical libraries, and in one case a patents office. The internal R&D capacity gives these firms a technological edge over other competing firms in the industry.

Some firms may not have large research facilities but may still undertake significant technical analysis, testing, and equipment modification at the mill level to improve product and process control, overall efficiency, and/or product quality and consistency. The knowledge and technology created by this local level activity is important and can make a significant contribution to increases in productivity. However, the knowledge is difficult to define and measure; it is often tacit, incremental, and embodied in the acquired knowledge, experience, and skills of employees.

Firms also support (and benefit from) R&D done by external researchers; they contribute to research cooperatives, fund research conducted by external interests (such as universities, or contract researchers), and provide in-kind services to research agencies. If there is a contractual arrangement, the results of externally supplied research may be proprietary. In the case of R&D conducted by research cooperatives, the research services and results are generally made available to all member firms that support the partnership.

Table A2.1 An overview of the Canadian forest sector S&T system.

Main elements	Components
Forest products firms	*Examples:* MacMillan Bloedel Domtar Noranda Canfor Tembec
Cooperative research institutes	Paprican (Western and Eastern Laboratories) Forintek (Western and Eastern Laboratories) FERIC (Western and Eastern Divisions)
Government of Canada	Industry Canada, Forest Industries and Building Products Branch Natural Resources Canada, Canadian Forest Service
Provincial forest management agencies	British Columbia Ministry of Forests, Research Branch OMNR, Centre for Northern Forest Ecosystem Research OMNR, Ontario Forest Research Institute
Provincial research councils	Science Council of British Columbia Alberta Research Council (ARC) Centre de recherche industrielle du Québec (CRIQ)
Advisory, coordinating, partnership, or funding bodies	Alberta Forest Research Advisory Committee British Columbia Forest Products Research Network Forum Canadian Model Forest Program Forest Renewal British Columbia Manning Diversified Forest Products Integrated Resource Fund National forestry research advisory bodies The Quebec Forest Research Council
Universities with schools of forestry	University of British Columbia University of Northern British Columbia University of Alberta Lakehead University University of Toronto Université Laval University of New Brunswick Université de Moncton
University-situated forest products research and education centres	Pulp and Paper Centre, University of British Columbia Centre for Advanced Wood Processing, University of British Columbia Pulp and Paper Centre, University of Toronto Pulp and Paper Research Centre, McGill University Research Unit on Industrial Flow Processes, École Polytechnique Limerick Pulp and Paper Research and Education Centre, University of New Brunswick Wood Science and Technology Centre, University of New Brunswick
Network Centres of Excellence	Mechanical and Pulps NCE, Paprican / McGill University Sustainable Forest Management NCE, University of Alberta

(Continued…)

Table A2.1 An overview of the Canadian forest sector S&T system. *(Continued)*

Main elements	Components
Various types of government R&D instruments	Contributions to technology partnerships
	Government–industry joint technology development ventures
	Intellectual property rights legislation
	Procurement
	Infrastructure
	Repayable loans
	Research funding through stumpage surcharges
	Refundable or non-refundable R&D tax credits (reducing tax payable)
	Subsidies, grants, and contributions to firms
	Tax deductions (i.e., reducing the amount of income subject to tax)
	Examples of generally available support programs: • Industrial Research Assistance Program • Canadian Technology Network • Technology Partnerships Canada • Foundation for Innovation
Other organizations	Engineering and private research companies
	Environment departments, federal and provincial
	National Research Council of Canada
	Natural Sciences and Engineering Research Council of Canada (NSERC)
	Machinery and equipment manufacturers e.g., CAE Machinery, Newnes, Hymac
	Social Sciences and Humanities Research Council
International scientific research	The BOREAS project

The Canadian forest industry also provides some support for forest management related R&D. For example, Alberta's Manning Diversified Forest Products Integrated Resource Fund provides funding to researchers studying the boreal forest. The fund is supported by a payment of a set fee per cubic metre harvested by some forestry firms in Alberta. Firms also conduct or support forestry research on management issues that pertain to their particular areas of operations. Firms also contribute to other partnership initiatives that support forestry-related research including the Model Forest Program and the Sustainable Forest Management Network Centres of Excellence.

Research Cooperatives

The Canadian forest sector S&T system includes three non-profit, industry–government supported, cooperative research institutes: Paprican, Forintek, and FERIC (Forest Engineering Research Institute of Canada). Each of the organizations has an eastern division (with facilities located in the province of Quebec), and a western division (with facilities located in Vancouver, British Columbia). These organizations obtain their revenues by a combination of annual membership fees from member firms and forest products industry associations, contributions from the federal and provincial governments, fees for contract research and consulting services, and fees for technical services provided to individual companies. Table A2.2 provides an overview of the total annual revenues earned by each organization and the area of specialization of each organization.

Paprican is the largest of the three agencies. It has an impressive record of research accomplishments over its period of existence. Paprican has two broad mandates: to undertake research and to increase the availability of skilled and knowledgeable specialists in pulp and paper technologies to the industry through education programs. The primary source of funding for Paprican is through

Table A2.2 Annual revenues and areas of specialization of Canada's industrial research cooperatives.

Organization	Annual revenues ($, millions)	Area of specialization
Paprican	33.4 (1995)	Supports the technical requirements of the pulp and paper industry in the areas of environmental technologies, cost competitiveness, and product quality and value.
Forintek	14.5 (1995)	Supports the technical requirements of the solid wood products industry[a]. Main areas of activity: market support, manufacturing technology, forest resource characterization, and technology transfer and technical services.
FERIC	7.6 (1996)	Focuses on operational and environmental aspects of technologies used in the harvesting and transportation of timber and post-harvest silvicultural operations.

[a]For example lumber, plywood, oriented strandboard, particleboards, laminated veneer lumber, and various producers of value-added products.

contributions from member companies. The federal government provides the agency with infrastructure and facilities and member companies with tax incentives. Paprican also has close ties with a number of universities including McGill, École Polytechnique, and the University of British Columbia (UBC). These ties occur in a variety of ways including joint development and implementation of a national educational program in pulp and paper technology; collaborative research and support for graduate students through the pulp and paper centres at UBC and McGill; leadership of the Mechanical Wood-Pulps Network of Centres of Excellence and support for an NSERC (Natural Sciences and Engineering Research Council) industrial chair on Industrial Flow Processes at École Polytechnique.

Paprican's in-house research capacity is located at its research facilities in Point Claire, Quebec, and Vancouver, British Columbia. In-house research is organized into three broad areas: environment, cost competitiveness, and product quality and value. The research is managed in a way that supplements and supports the internal R&D activities of its member companies.

Forintek is the second largest of the three cooperative research agencies. Its head office is in Vancouver; it has research facilities in both British Columbia and Quebec and technology liaison offices in other provinces. Forintek's research focus is on the solid wood products industry (for example, lumber, plywood, oriented strandboard, particleboards, fiberboards, engineered wood products). Forintek differs from Paprican in a number of ways. First, it has a larger number of member companies but generally (although not exclusively) these companies are small to medium-sized enterprises that do not have in-house R&D capabilities. Second, government contributions account for a significant percentage of the total annual revenue of Forintek: six provincial governments plus the federal government provide an annual contribution to the organization. Third, the organization has fewer connections with universities but stronger connections with provincial research councils. Fourth, the activities of the organization tend to focus more on the important operational requirements of member companies and less on the long-term strategic requirements of the industry.

Forintek science and technology activities are oriented to pre-commercial technology development, technology transfer and technical services. Its research program focuses on market support research (for example, product testing for grading purposes), manufacturing technology, forest resource characterization, and technology transfer and technical services. Given the large number and diversity of its member companies and government sponsors, significant attention is paid to planning, managing, and reviewing Forintek's activities. The organization has implemented a sophisticated program management and review system that involves a board of directors, a National Research Program Committee, and five National Technical

Advisory Committees responsible for setting priorities, selecting projects, and monitoring progress.

The cost of accessing, harvesting, and transporting raw materials, and managing the forest is a significant part of the total cost of producing forest products. Major technological changes have occurred in forest harvesting and silvicultural operations over the last 20 years with a strong emphasis on increasing mechanization. **FERIC** provides technical services relative to the technological needs of the woodlands divisions of Canadian forestry companies. FERIC's R&D programs are described in the following:

> FERIC's R & D programs cover the engineering, human, operational, and environmental aspects of harvesting, processing and transportation of forest products; silvicultural operations; and the specific problems encountered in small scale operations. In addition, we conduct contract research on projects selected for their value to our partners. FERIC's research is field-oriented, and is carried out in close cooperation with woodlands personnel. Our research focuses on the following areas: wood harvesting, transportation and roads, silvicultural operations, small-scale operations, and engineering design/specialized technologies (FERIC web site: http://www.feric.ca)

Government of Canada

The federal government maintains a broad range of programs to encourage science and technology, promote R&D, and increase the rate of innovation of Canadian business. These programs are administered by a number of different departments and federal agencies. The two principal agencies that most directly influence science, technology, innovation, and improved management practices in the Canadian forest sector are the Forest Industries and Building Products Branch (Industry Canada) and the Canadian Forest Service (Natural Resources Canada).

The **Forest Industries and Building Products Branch** monitors key strategic issues affecting the forest products industry and ensures that departmental and federal policies reflect the needs of the forest industry and are supportive of the industry. One way that the Branch contributes to the forest sector S&T system is through strategic assessment of future technological requirements of the sector. For example, recently the Branch contracted FERIC to produce a major report entitled *Technology Road Map for Forest Operations in Canada* (FERIC 1996). This study "identifies starting and destination points, discusses the driving forces, presents opportunities for technological improvement, and provides recommendations on the best road to select for the future."

The Canadian Forest Service (**CFS**) has a broadly based mandate that includes non-S&T-related initiatives (such as international forestry, industry liaison, trade policy support, national statistics and databases, First Nation Forestry Program, Tree Plan Canada, national forest policy development, and reports to Parliament on the state of Canada's forests) and S&T-related activities. However, forest-related S&T has historically been, and is currently, the main function of the CFS. The four main CFS program areas that support forest-related S&T are the CFS Science Program (which is organized into 10 national S&T networks); the Model Forest Program (which is a multipartnered program that promotes the development, testing, and demonstration of state-of-the-art forest management techniques across a system of 11 national model forests (which includes Waswanipi, an Aboriginal model forest); a program of partnerships to define and implement national forest science policy; and a program to support industrial research cooperatives (either through provision of facilities or by annual financial contributions). The CFS delivers its science program through five research facilities located in Victoria, Edmonton, Sault Ste. Marie, Québec City, and Fredericton. National science policy, the Model Forest Program, and contributions to the cooperative research institutes are managed and delivered through the Headquarters office in Ottawa. CFS research priorities are established through a series of advisory committees that involve clients and stakeholders. The following is extracted from the CFS web page which is accessible through the NRCan web page (http://www.nrcan.gc.ca):

> Canada is becoming a world leader in sustainable forest management. The Canadian Forest Service (CFS) of Natural Resources Canada has, for the

last century, provided the Canadian forest sector with leading-edge forest science and expertise. Through cooperation and partnerships with clients across Canada, the CFS offers:

- innovative approaches to sustainable forest management practices;
- technologies and systems for collecting and integrating information; and
- scientific, technical and policy advice for national and international initiatives.

The CFS has a long tradition of excellence in scientific research. Science and technology initiatives focus on two key areas: understanding forest ecosystems and developing strategies for advancing sustainable forest management.

Provincial Forest Management Agencies

Examples of forest management agencies from the two provinces with the strongest in-house research capability related to forest resources, British Columbia and Ontario, follow.

The Research Branch of the **British Columbia Ministry of Forests** is organized into three sections: the Forest Practices Research Section, the Forest Biology Section, and the Forest Productivity and Decision Support Section. Funding for research initiatives conducted by the Research Branch is obtained either internally, or from the Forest Renewal B.C. Research Program. The research is guided by the needs of British Columbia's comprehensive Forest Practices Code and by its corporate objectives and priorities.

The **Ontario Ministry of Natural Resources** has two research organizations that provide in-house R&D capability relative to the sustainable management of Ontario's forest resources: the Ontario Forest Research Institute (at Sault Ste. Marie), and the Centre for Northern Forest Ecosystem Research (at Lakehead University, Thunder Bay). The Ontario Forest Research Institute science programs address a range of issues including forest landscape ecology; genetic resource management; forest growth and yield; ecological land classification; vegetation management alternatives; silviculture of boreal, Great Lakes, and St. Lawrence ecosystems; ecosystem health, productivity, and diversity; interrelationships between aquatic and terrestrial ecosystems; and intensive plantation ecology and management.

The Ontario Ministry of Natural Resources's Centre for Northern Forest Ecosystem Research is closely affiliated with the Faculty of Forestry and the Department of Biology at Lakehead University. The mandate of the center is to study the effects of forestry practices on boreal forest aquatic and terrestrial ecosystems with the general objective of evaluating whether Ontario's Timber Management Guidelines meet their intended objectives in terms of impacts on fish habitat, moose habitat, and tourism values.

Provincial Research Councils

Most provincial governments have science councils that encourage and promote science and technology related to resource management and industrial technologies. However, these research councils vary in terms of the degree to which research is targeted to specific economic sectors (such as the forest sector) and the extent to which research is encouraged through in-house research versus through grants and contributions to research conducted by firms or universities. The following provides a short overview of provincial research organizations in Quebec, Alberta, and British Columbia and demonstrates the range of approaches employed by these organizations to promote science and technology and innovation within their provinces.

The provincial agency responsible for enhancing industrial technology in the province of Quebec is the Centre de recherche industrielle du Québec (**CRIQ**). CRIQ undertakes a number of activities to develop and apply new technologies, to provide technical services to individual enterprises, and to assist companies to determine their technological requirements and opportunities through technology assessment. CRIQ does target some of its activities to the development, application, and evaluation of technologies in the wood products sector and to the provision of technical services to Quebec forest products companies. The wood products engineering team at CRIQ has expertise in various areas such as optimization of production processes to increase fiber utilization and development of manufacturing technologies in the wood products sector. CRIQ also provides technical services, technology assessment services, and feasibility assessments to individual wood products companies and sawmill operators and will in some cases undertake local R&D at a mill site on behalf of individual companies.

The Alberta Research Council (**ARC**) is a significant research performer relative to the development of knowledge and technologies that support Alberta's forest products sector and sustainable forest resource management. ARC has significant in-house research facilities located in Calgary, Edmonton, and Vegreville. The one in Vegreville, the Alberta Environment Centre, was recently transferred from the Department of Environmental Protection to the Alberta Research Council. It provides some sustainable forestry research on behalf of the province.

ARC also has a significant forest products sector R&D capability. ARC has product and process development expertise in the areas of engineered wood products, wood composites, alternative fibers, pulp and paper production, experts systems applications, fiber-loss reduction, alternative uses for sludges, improved effluent treatment, and decision support system applications. ARC has a number of functions. It provides technical services to Alberta companies by providing access to a Standards Council of Canada accredited product evaluation laboratory for wood products; a product development pilot plant for wood structural panel development; advice and technical and/or research assistance in the areas of wood composites; and research into solid woods and alternative fibers.

ARC also undertakes in-house R&D and has achieved success in areas such as the development of techniques for the application of composted pulp and paper sludges for soil enhancement; improvements in Alberta's mechanical pulping mills in the operation of aeration basins, characterization of control and pitch, and advanced sensing techniques for control of refiners; enhanced control of continuous digesters in kraft mills by application of nonintrusive techniques for measuring density and the characterization of wood extractives; the development of a unique system that monitors pressing parameters of composite panel products; and the development of a system for online machine stress rating testing of oriented strandboard.

The **Science Council of British Columbia** provides financial support for proprietary research conducted by individual companies (up to 50% of the eligible costs) as well as for collaborative research involving commercial interests and researchers from academic institutions in British Columbia. Project proposals are considered under various economic sectors of importance in British Columbia including forestry and forest products. Peer review committees with expertise in forestry and forest product S&T are used to evaluate and prioritize funding requests. The Science Council also administers Forest Renewal British Columbia.

Universities with Forestry Schools and Forest Research Capacity

There are eight Canadian universities with strong forestry or forestry-oriented renewable resource management programs in Canada. Universities contribute to knowledge creation and improved methods of management in a number of ways. Through their education programs, they supply skilled professionals into the marketplace. They perform research through the work of both graduate students and academic staff. They contribute strongly to the management of S&T processes and science policy development by contributing to advisory bodies, coordination mechanisms, and policy task forces. They are a conduit for accessing scientific knowledge and information developed in the academic community at large. They administer, control, and contribute to research networks (such as the Sustainable Forest Management Network of Centres of Excellence at the University of Alberta). The eight universities are

- University of British Columbia, Faculty of Forestry, Forest Resources Management Department, Wood Science Department, Forest Science Department, Vancouver, British Columbia.
- University of Northern British Columbia, Faculty of Natural Resources and Environmental Studies, Forestry Programme, Prince George, British Columbia.

- University of Alberta, Faculty of Agriculture, Forestry and Home Economics, Department of Renewable Resources, Edmonton, Alberta.
- Lakehead University, Faculty of Forestry, Thunder Bay, Ontario.
- University of Toronto, Faculty of Forestry, Centre for Landscape Research,
- Université Laval, Faculty of Forestry and Geomatic, Wood and Forest Science Department, Laval, Quebec.
- University of New Brunswick, Faculty of Forestry and Environmental Management, Fredericton, New Brunswick.
- Université de Moncton, École de sciences forestières.

University-Situated Forest Products Research and Education Centers

There are a number of forest products research and education centers situated on university campuses across Canada. These centers collectively perform a range of functions including long-term, scientific research with commercial applications; continuing education; extension services; undergraduate teaching; graduate student training and research; technical support and consultation services for companies; collaborative research with industrial partners; feasibility assessments of new technologies; pilot plant operations and services; testing facilities and services; multidisciplinary research including biotechnology applications; and information acquisition, synthesis, and dissemination.

The various university situated forest products research and education centers in Canada include:

- University of British Columbia, Pulp and Paper Centre
- University of British Columbia, Centre for Advanced Wood Processing
- University of Toronto, Pulp and Paper Centre
- McGill, University, Pulp and Paper Research Centre
- École Polytechnique, NSERC/Paprican Industrial Research Chair on industrial flow processes
- University of New Brunswick, Wood Science and Technology Centre
- University of New Brunswick, Limerick Pulp and Paper Research and Education Centre

BOREAS Project

As concerns grow about the capacity of atmospheric, oceanographic, and biological systems to absorb and assimilate the by-products of economic development and population growth, scientific research will increasingly take on global importance. In the mid-1990s, a major international experiment called the Boreal Ecosystem-Atmosphere Study (BOREAS) was initiated in northern Saskatchewan and Manitoba.

The results of the BOREAS project potentially may have significant implications for Canadian society, resource management agencies, and Canadian industry. Investments in forest management and in large-scale, billion-dollar processing facilities are long term in nature and there is some risk and uncertainty associated with these investments due to a lack of information about the future productivity and characteristics of forest resources. The BOREAS project may provide valuable insights that will have implications for how we manage forests, investments in forest development, and long-term competitiveness of the forest industry in Canada. Perhaps more importantly, however, the BOREAS project shows that it is possible to bring large numbers of experts from multiple disciplines together to develop and undertake a large-scale, problem specific analysis.

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