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Cooperative R&D and the Canadian Forest Products Industry

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In the past decade the share of cooperative R&D has increased. In this paper, using a case study of the forest industry in Canada, the antecedents of cooperative R&D and the forms it take are investigated. We show how market failures are corrected in the industry largely through industry wide R&D consortia. The share of government funding to maintain the cooperation reflects the degree to which the consortia can appropriate the full value of their knowledge products (i.e. prevent spillover of innovations to non-members in Canada and elsewhere). The case study indicates that the prime role of these nationwide consortia is the provision of potential access to R&D expertise, technological intelligence, and technology transfer services. The success and stability of these consortia depend on the degree to which their governance systems allow for better alignment of the costs and benefits that accrue to members from the consortia. Copyright © 2003 John Wiley & Sons, Ltd.

INTRODUCTION

Cooperative research and development (R&D) has been broadly defined as an arrangement under which firms jointly acquire technical knowledge (Link and Bauer, 1989). Across most industries in recent years there has been a general increase in inter-firm cooperation in joint research and development (R&D) while the share of individual R&D has declined (Tao and Wu, 1997). Several authors have explained this trend by pointing to the growing scale of R&D expenditures now required that make it more costly and risky for firms to pursue such programs individually and to the development of industrial policies that favor cooperative research (Bleeke and Ernst, 1993; Kumar and Magun, 1995; Rood, 2000).

In this paper we explore the antecedents to cooperative R&D and the organizational forms of cooperative R&D through a case study of the forest products industry in Canada. We start the paper by examining the characteristics of R&D activities in general and identify some key causes of market failure that can be overcome through cooperation (the next section). In the third section we discuss the various motives that prompt firms and other organizations to participate in cooperative research activities. In the fourth section we describe the alternative forms of R&D cooperation that have emerged and their functional characteristics. On the basis of the economic literature, we articulate a set of hypotheses about why and how firms in an industry might collaborate in R&D in the fifth section. The sixth section presents the case study of cooperative R&D behavior in the Canadian forest products industry. In the last section we discuss the insights gained from the case study and their implications for theory building and practice.

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THE CHARACTERISTICS OF R&D AND THE PROPENSITY TO COOPERATE

The extent to which firms will engage in R&D depends on the value of the information they hope to acquire through their efforts and their ability to fully appropriate that value. There is a tendency for underinvestment in R&D because of the difficulty in appropriating the full value of R&D products due to asymmetries of information, economies of scale, uncertainty, and 'spillover' to other firms (Spence, 1984).

The extent to which spillover exists depends upon both the characteristics of the particular R&D product and the means available to appropriate its value. The spillover may be quite large if the technology or product developed by R&D is easily copied, or quickly becomes available to competitors through public means when protection of ownership rights is not effective. In addition to market failures resulting from externalities, asymmetries in information make it difficult for those generating innovations to appropriate their full value through licensing.

The presence of economies to scale and scope and market power effects may also be causes for market failure. Small, undiversified companies with no market power are less likely to invest in R&D than larger companies or those with a broader range of products (Aghion and Tirole, 1994). Cooperative R&D may internalize externalities and help small and medium companies enjoy economies to scale and scope. Cooperative research may also improve the flow of information between suppliers and customers of firms (Clark and Fujimoto, 1991; Handfield *et al.*, 1999) and between public sector (e.g. universities and government laboratories) and private sector R&D establishments. Governments may see cooperative R&D as a possible solution to underinvestment in R&D and as a means of facilitating information flows to and from the private sector. Universities may seek partnerships with the private sector and the government to obtain additional funding, provide training opportunities for students, and gain access to industrial facilities, equipment, and government laboratories (Link and Bauer, 1989).

What Motivates Firms to Join Cooperative R&D?

There are several fundamental reasons why firms collaborate in R&D, In general, firms engage in cooperative R&D to:

1. Internalize externalities;
2. Pursue R&D cost reduction;
3. Gain expertise and information;
4. Share risks; and
5. Coordinate strategies.

A number of economic models have addressed how internalizing spillover can rectify (at least in part) the incentives problem firms face in pursuing individual R&D. Spence (1984) shows that cooperative R&D can, in part, overcome the incentives problem by internalizing spillovers and reducing redundancy in R&D funding. d'Aspremont and Jacquemin (1988) showed that the size of the spillover effect is important in determining the overall level of R&D, and that cooperative R&D will lead to greater innovation than competitive R&D in the presence of significant spillover effects. Katz (1986) modeled the level of R&D under cooperative research consortia as a function of the differences in spillovers between members and non-members and the degree of competition in the end product market. The benefits of membership come through the effective level of R&D, which is the sum of the firm's own expenditures plus R&D spillovers. It is shown that cooperative R&D internalizes the cost of spillovers thus reducing the cost of R&D to the firm. Cooperative R&D may also reduce competitor's costs, which in turn will reduce the competitive benefits of R&D to the firm. The more intense competition is in end product markets the more consumers will benefit, reducing the benefits of R&D to firms (to the point that under perfect Bertrand competition the incentives for R&D are eliminated).

Kamien *et al.* (1992) examined a model where firms choose to either compete or coordinate their R&D expenditures and whether to share information or not. They find that coordination of R&D and full sharing of information maximize consumer and producer surplus.[1] Kamien and Zang (2000) postulated a model in which the effective level of R&D depends upon the firm's investment in its own R&D in order to take advantage of externalities generated by other firms' R&D. In the absence of cooperative agreements, firms will pursue more firm-specific approaches to limit spillover, which reduces the effectiveness of overall R&D and thereby lowers firm profits. They suggested that this might provide a motive for the endogenous formation of cooperative R&D in an industry organized around common purposes.

Bransetter and Sakakibara (2000) empirically tested the predictions of the various models described above using evidence from Japanese research consortia by examining the amount of patenting activity by research consortia members. They found, as predicted, that increased spillover within research consortia are related to positive outcomes (increased patenting following participation in the consortia) and that product market competition has an influence as predicted (though it is not statistically significant).

R&D Cost Reduction as a Motive

There are several ways in which firms might be able to reduce the costs of R&D through collaboration. They may be able to jointly share the cost of research efforts. There may also be limited resources (such as trained personnel) or there may be economies of scale (such that the marginal cost of research falls with the size of the research effort). In such circumstances, it might be significantly more costly for firms to pursue research individually, and the costs of such research can be reduced through collaboration (see Goel, 1999, Murphy, 1991; Baldwin *et al.*, 2000). Inter-firm differences might also influence the motives of firms in choosing to participate in cooperative R&D. Larger firms are likely to have their own R&D departments, and may look at cooperative R&D as a complement to their own R&D. Indeed, in a survey of firms that undertook cooperative R&D, Link and Bauer (1989) found that cooperative R&D had a positive impact on the productivity of internal R&D, and as one reason that firms cited for entering into cooperative R&D. Smaller firms may look at cooperative R&D as a substitute where they lack their own personnel. Governments may seek cooperative R&D as a means of correcting market failures efficiently. Government funding reduces costs of R&D to members of such cooperative ventures thus increasing their incentive to participate.

Gaining Expertise and Information as a Motive

Firms can also gain access to expertise and information through collaborative arrangements that might otherwise be more costly or inaccessible. Firms might seek partners with either expertise or knowledge in a particular area that they lack, such as suppliers of specialized manufacturing processes, or customers' preferences within a new market. Anderson (1995) divides cooperation into three principal modes: *research-oriented collaboration*, in which firms join together to tap one another's resources without having to employ a 'critical mass' of researchers (a cost reduction argument); *technology-oriented collaboration*, when a firm seeks another to tap its expertise in an existing technology; and *market-oriented collaboration*, when a firm seeks another to gain access to markets they would otherwise be unable to enter.[2] Anderson investigated firm collaboration in the Canadian aerospace industry which is strongly export-oriented and found that market-oriented collaboration is the most important type inter-firm relationship in the Canadian industry. He attributed this to the small size of the domestic market that increases Canadian firms' reliance on export markets.

Coordinating Strategies as a Motive

Ruiz-Mier and Talavage (1989) show under a model of strategic trade that cooperative R&D can improve the position of domestic firms relative to foreign competitors in international markets. Firms may also choose to work together to coordinate strategies that they might otherwise be unable to do in the absence of the cooperative framework. An example would be the development of industry standards, where a common standard benefits all firms within an industry (through providing information to the market that helps buyers identify the characteristics of the good reducing the need for firms to supply the information individually on an *ad hoc* basis). This is also an example where there are significant externalities associated with its creation since the value of the information lies in its broader dissemination.[3]

This may also lead to potentially anti-competitive actions where coordination in research may lead to coordination in other decisions, facilitating arrangements to coordinate pricing or market share. Firms that face regulatory constraints may choose to cooperate to retard or delay innovation.[4] This possibility has long been a concern of antitrust law (Goel, 1999; Murphy, 1991).

Risk-sharing as a Motive

Firms may also choose to work together to reduce the risk of unsuccessful R&D. The risk may come from the commercial failure of a new product, new process, or the capital cost of a new facility or venture seeking to utilize new technology or enter new markets.

FORMS OF COOPERATION

Firms can organize their business activities using a number of different contractual arrangements. Hart and Moore (1990) and Williamson (1985) have examined the circumstances under which organizations will internalize relationships within the firm as opposed to relying on market transactions. They have argued that the critical factor is the ability to form complete contracts; where there is uncertainty or an inability to make complete contingent contracts, or the cost of doing so is too high, firms will internalize those contracts (Nakamura and Xie, 1998). The alternative to arms-length market transactions is not necessarily complete internalization. Broadly speaking, there are four forms that offer different degrees of flexibility in cooperative ventures with the associated advantages and disadvantages:

1. Short-term contracts;
2. Long-term contracts;
3. Relational-contracting; and
4. Research joint ventures.

These offer different (1) degrees of control over decision-making, (2) levels of exposure to opportunism, and (3) levels of transaction, monitoring, and enforcement costs. The different organizational forms accommodate alternative governance mechanisms (i.e. the rules that govern the co-operative venture). In general, an optimal governance system from the perspective of all participants is one that maximizes expected outcomes and minimizes transaction, monitoring, and enforcement costs and allocates benefits and costs in a way acceptable to all partners.

Short-term Contracts for R&D Cooperation

Short-term contracts are arms-length market transactions. Contracts specify the terms of exchange. Writing a contract requires (1) the information or technology must be codifiable or capable of being transmitted in whole from one party to the other; (2) there should be predictability or certainty about what is to be exchanged (too much uncertainty makes it difficult to write a complete contract that takes into account all the possible contingencies and outcomes; and (3) the contract should be enforceable and easily monitored. Short-term contracts minimize risk and the possibility of opportunism; however, they are extremely difficult to write (and monitor and enforce) when there is a great deal of uncertainty about future outcomes.

Long-term Contracts

Long-term contracts are similar in their requirements except that they offer some scope for learning and adjustment in the process of carrying out R&D (so that the parties can periodically renegotiate based on information they acquire during the terms of the contract).[5] Again it requires codifiable information. Long-term contracts are necessary where there are large investments required in specific assets (to minimize the likelihood of hostage taking and loss of bargaining power by the party with the most significant investment in specific assets).

Relational Contracting

Over time, firms may be able to develop a relationship that forms the basis for more discretion in molding future relationships (instead of specifying through a contract). Relationship-based contracts offer a way for firms to deal with complex situations where there is more uncertainty and less codifiability. However, such contracts involve less effective monitoring and enforcement and thus require trust between the contracting parties.

Using transaction cost economics Ring and Van de Ven (1992) investigated the choice between four different types of governance systems: discrete contracting (comparable to short-term contracts); recurrent contracting (comparable to long-term contracts); relational contracting; or hierarchical managerial transactions (internalizing within the firm through a merger). They argue that the two most important factors that determine the choice are the relative degree of risk and trust embodied in what the firms hope to accomplish.[6] They note that parties with a history of successful transactions are less likely to suffer adverse affects of information asymmetry. They further claim that high risk, high reliance relational contracts provide greater transaction flexibility, since contracts need not be rigidly specified and are therefore better suited to changing needs, and that it is under these types of relationships that firms can most effectively carry out joint R&D.

Research Joint Ventures and Consortia

A Research Joint Venture (RJV) has been narrowly defined as the formation of a new entity jointly controlled by at least two firms for the purpose of conducting R&D (Link and Bauer, 1989). More broadly speaking, the definition can be expanded to include research consortia, where firms jointly fund research and in which they may or may not have equity stakes. The RJV may be vertical (between independent researchers and manufacturers) or horizontal (where manufacturers that may be competitors pool resources) (Brodley, 1982). The size, membership characteristics, and goals of the research all vary across RJVs.[7]

The creation of an independent organization creates a mechanism for joint decision-making (so that not all contingencies have to be pre-determined) and reduces the reliance upon trust required under relational-based contracting. RJVs may involve high transaction and monitoring costs as well as create principal-agency problems as firms contribute assets to the partnership over which they do not exert complete control. In addition, a significant problem facing RJV is the sharing of rewards from innovation. Active partners face a moral hazard in revealing information to passive partners; there may also be problems if research results in innovation with unexpectedly high benefits (Goel, 1999). Antitrust concerns have also been raised about RJV since, in concentrated markets, they may lead to decreased competition as firms use RJV to jointly retard innovation (thereby protecting profitable markets) or coordinate production or market share arrangements (Tirole, 1988).

The organization may be funded through the contribution of equity, membership fees, and other sources of funding such as government grants. The contribution of equity can help reduce in part some of the incentives problems by reducing potential opportunism and providing a basis for decision-making. Ring and Van de Ven (1992) describe how some of the organizational components of joint ventures (although they do not explicitly describe it as such) can compensate in part for a lack of trust:

> 'High-risk relational transactions in which parties may still be learning to rely more heavily on trust are likely to make extensive use of hostages and collateral as a means of reducing risk otherwise surrounding a lack of exclusive control over idiosyncratic assets. In such cases the parties may seek to guard against risks related to a lack of information or information asymmetry by requiring repricocity. These forms of consultation may not be sufficient in cases in which heavy investments in idiosyncratic physical or site-specific assets are involved in the transaction. In such cases, control risks may be safeguarded by requiring partial financing through equity collateral, or by the exercise of voting rights that accompany equity positions or membership on a board of directors.' Ring and Van de Ven (1992)

Leyden and Link (1999) have explored the composition of RJV and found that government laboratories more often are members of large RJV.[8] They attribute this to several factors: first, the payoffs from membership to a RJV decreases as the number of members increase (since the benefits of the research output must be spread across more members), and members face the increased risk of free-riding and opportunism as some firms try to manipulate the activities of the RJV for their own benefit.[9] The participation of government laboratories alters the rates of return for members in three ways: (1) they increase economies of technological scope; (2) they decrease the ability of member firms to appropriate the output for their own uses; and (3) they affect the cost of participation in the RJV (although it is not clear in what direction). They argue that the economies of scope come about from an ability to utilize human and technical capital that is rarely available in the private sector, thereby increasing the returns to R&D. The decreased ability results from government laboratories focus on basic research and an emphasis on publication (making it more difficult to appropriate the value of R&D output). In terms of costs, they argue that there are several factors at work; participation may reduce member costs because of the contribution and the potential for the government partner to act as an honest broker to reduce monitoring costs and discourage opportunism.[10] On the other hand, participation may raise costs to the extent there are additional costs associated with the government infrastructure or required by government participation (in terms of publication and disclosure).

Empirical Evidence on Cooperative R&D Arrangements

Several authors have looked at what factors influence how firms collaborate (both in terms of how the endeavor is organized and how successful it is). Steensma and Corley (2000) investigate the relationship between technology attributes and firms' choice of how to organize partnership linkages through a survey that measured firm satisfaction with partnership outcomes. They argue that the uniqueness, imitability, and uncertainty of the underlying technology being sought determine the relative success for firms using three different modes of partnership which they rank in decreasing order of organizational interdependence: acquisition; joint development; and licensing.[11] They hypothesize that more unique, the less imitable, and the more certainty the more likely successful partnerships will be tightly coupled in the form of acquisitions (because firms are better able to capture all the potential value of the technology). Licensing is more suitable for projects in which there is uncertainty and firms want to minimize their commitment. They find that the evidence supports their hypotheses for imitability and uncertainty but not for uniqueness in terms of successful outcomes.

Bleeke and Ernst (1993) found in a survey of collaborative joint ventures that flexibility and an ability to evolve were a hallmark of successful collaborative endeavors. They also find that 'the lowest success rate for alliances is when two partners bring competing products to the same distribution channel' and that the risk of failure is significantly increased when partners' strengths are not matched. Bransetter and Sakakibara (2000) also investigated the organizational characteristics of the consortia, and found that the more basic the research, the more positive the outcome, and that pre-existing technological strength in the research area was important as well. They found that the level of expenditures in determining R&D outcomes was insignificant, and interpret this as meaning that the design of the consortia rather than the level of funding was more important.

Nakamura *et al*. (1997) investigated the issue of trust in how it affects the choice of governance mechanisms. They point out that there is a gradation of governance mechanisms based on trust, which can be listed in increasing order of trust:

- Economic cooperation (cost-sharing);
- Structural cooperation;
- Relational governance; and
- Strong form trust.

They then show how cultural norms in the US and Japanese create different levels of trust which in turn support the choice of particular governance structures within each country.

Protecting Information

The benefits in cooperative R&D will accrue from the information acquired through members' expenditures. In the case of an RJV, members have to decide how to assign ownership to any innovation resulting from research as well as decide which information to pursue. There are various ways a RJV can protect the information it develops and the value it has for members; it can attempt to restrict the information to others by making it only available to members; it may choose to make it available to others outside of the RJV through licensing; or it may make it freely available to members and non-members alike.

Circumstances under which firms might license out innovations include situations in which another firm can obtain higher value from the innovation or product market competition is softened by differentiation (either geographic or product) so that overall profits increase despite the competition; or in the case of strategic licensing, in which a firm licenses its technology to reduce the incentive for rivals to 'invent around' the technology (Tirole, 1988).

Tao and Wu (1997) investigate the issue of licensing given two different types of cooperative research arrangements, research joint venture (RJV) and non-equity co-development (COD). The two differ in the ownership of the innovation. Under RJV the technology must be licensed by members who pay a royalty fee while under COD there is no licensing by members who are instead free to use the technology with no payments. Their model, supported by empirical evidence, shows that the characteristics of the downstream industry determine the choice. When firms are competitors, and expect to use the technology developed in their downstream business, they will choose the RJV since the expected profits help them coordinate production strategies and thereby increase profits. They do not use COD since in the absence of royalties, competition between the firms will drive profits down as production increases.

HYPOTHESES ABOUT COOPERATIVE R&D IN A PARTICULAR INDUSTRIAL SECTOR

The discussion in the preceding sections indicated that the extent of cooperative R&D in a sector is a function of: (1) the characteristics of the demand for final products in the industrial sector; (2) the industrial organization of the sector; (3) the nature of the R&D activity, the characteristics of the innovations it may produce and the supply of the R&D; and (4) government policies regarding cooperative R&D.

In sectors characterized by inelastic demand for final products innovations leading to cost-cutting may create advantages if such innovations increase the competitive advantage of innovators who can drive out competitors. Innovations which are widely diffused will increase competition and their benefits will be captured by customers. Thus cooperative ventures for process R&D aimed at cost-cutting will be limited.

Hypothesis 1: In sectors with inelastic demand the incentives for cooperative process R&D aimed at cost reduction are limited.

We may expect, however, to find cooperation in process R&D when special circumstances affect the competitiveness of a defined group of companies with limited market power. This may be the case when specific regulatory measures (e.g. pollution emission controls) affect a group of firms in a particular region or firms that use special inputs or processes of production.

Generally a sector with high competition and many small firms will be likely to be less R&D intensive except when new technologies allow for product differentiation, The share of cooperative R&D of all R&D efforts, however, is likely to be higher especially when technological innovation is necessary to ensure the viability of the sector and R&D is expensive. Similarly small companies with restricted access to technological resources and expertise may seek to join cooperative ventures to ensure access to innovations.

Hypothesis 2: In an industry with a high degree of competition, small firms, and few opportunities for differentiation, investment in R&D will be lower although the share of cooperative R&D will be higher.

When an industry is characterized by a high degree of diversity of raw materials, other inputs and technologies, cooperative R&D between suppliers of inputs and customers allow for benefits of mutual learning and customization without a high degree of spillover.

Hypothesis 3: The higher the diversity of inputs and technologies the higher the incentives for cooperative R&D between suppliers of technology and manufacturers.

When technologies are standardized suppliers of equipment tend to create spillovers discouraging purchasers from sharing private information and innovations as these can be appropriated and benefit their competition. The nature of the R&D process and the characteristics of innovation may affect both the propensities to invest and cooperate. When innovations can be protected and their benefits fully appropriated through the market the incentives to invest in R&D will be higher while the share of cooperative R&D will be lower. When the protection of intellectual property is weak and thus the chance of spillover is high firms will have less incentive to invest in R&D but the share of cooperative R&D will be higher.

Hypothesis 4: A high degree of spillover increases the incentives to form inclusive R&D consortia to prevent free riding.

When the outputs of R&D are uncertain firms may join a collaborative venture to share risks and gain access to the information. This is the characteristic case in pre-competitive R&D.

Hypothesis 5: The share of cooperative R&D is likely to be higher in basic and pre-competitive applied R&D than in the competitive phases of R&D.

Government may play a crucial role both in constraining and encouraging cooperative R&D. Anti-trust legislation may make cooperation between firms illegal or at least subject to legal threats. On the other hand government subsidies to cooperative R&D may encourage firms to join R&D consortia.

Hypothesis 6: Government promotion of cooperative R&D may increase the incentives for firms to join cooperative ventures.

The choice of form for collaboration in R&D depends on: (1) the nature of the R&D process and the characteristics of its products; (2) the competitive relationships between collaborating firms; (3) the alignment of objectives with respect to the specific focus of the collaboration; and (4) the inter-firm and interpersonal network of relationships between collaborators and the general culture of trust. In situations where the outputs of R&D are predictable, codifiable, and verifiable and the R&D process does not involve large investments in specific assets, arms length short-term contracting will be an efficient mode of collaboration. Clearly if the outputs of R&D may significantly affect the core business of a firm it may choose to internalize the R&D activity. This will be more likely in situations where alternative suppliers of R&D are not available.

Hypothesis 7: When the expected outputs of the R&D are codifiable, predictable, and verifiable, and there are alternative suppliers of R&D, or when the R&D outputs may not affect the core business of the firm, then short-term contracts will be more likely when the R&D activity does not require significant investment in specific assets. When the R&D activity requires significant investment in specific assets, then long-term contracts to supply R&D services are more likely.

When the output of R&D is not codifiable, or where costs and benefits involved are difficult to predict or assess, arms-length contracts are difficult to negotiate. In such circumstances flexibility and discretion are necessary in managing the cooperative R&D. Relational contracts or independent R&D consortia (e.g. equity joint ventures or R&D corporations) will be the most likely forms of organization of the cooperative venture. Relational contracts provide a general framework for governance but expect partners to be flexible and change their expectations and the terms of the contract that guide cooperation in view of changing circumstances. Trust is the basic ingredient. Thus one would expect such form of contracting in situations where previous experience and trusting relationships were established between firms or strong social and legal sanctions against opportunism exist.

Hypothesis 8: Relational contracting is likely to evolve where the R&D process involves large uncertainty, lack of codifiability, and long-term inter-firm trust relationships that have been established or where strong environmental sanctions against opportunism may exist.

Where the R&D process is lengthy, and its costs and benefits are uncertain, and trust levels are not high, the preferred form of R&D cooperation would entail independence from its parents. An independent organization where benefits can be internalized and appropriated would reduce the risk of opportunism yet create the discretion and flexibility necessary to ensure long-term stability and success for the venture.

Hypothesis 9: Where trust levels are relatively low, competition is high and R&D processes and outcomes are uncertain, the most likely organizational form that the cooperation would adopt is one where the cooperation is entrusted to an independent organization (e.g. a joint-equity venture or an independently managed research corporation).

Clearly the success of such independent organizations lies in their abilities to protect their outputs from opportunistic exploitation by some of their members. Such organization must adopt governance structures which ensure that the allocation of costs and benefits is transparent and regarded as fair by the members.

Hypothesis 10: Successful independent research consortia (or joint equity ventures) develop equitable means of allocating the costs and benefits of their operations and effective means for appropriating the value of their innovation.

In the next section we explore the validity of these hypotheses through a case study of cooperative R&D in the forest products industry in Canada. We use the insight gleaned from the case study to develop grounded theory extending these hypotheses.

INTRODUCTION TO THE CASE STUDY

The Canadian forest products industry offers a good place to examine cooperative R&D. While firms within the industry share important similarities (they all tend to sell relatively homogeneous goods, with a high reliance on export markets) there are also important differences. Firms within the various sectors of the forest products industry utilize different technologies, manufacture different products, and those within a particular sector may also face local differences that can affect the type of goods they can manufacture. These similarities and differences offer an opportunity to examine the factors that contribute towards cooperative R&D.

We have utilized several sources of information to examine cooperative R&D. First, we have relied upon material drawn from the literature. We conducted a series of interviews with participants in the forest industry sector.[12] We also have used unpublished data from a survey conducted by Statistics Canada (2001) on innovation in Canadian manufacturing. Data from the survey on innovation are available by manufacturing sector for four different components of the forest products industry: (1) sawmills and wood preservation; (2) veneer, plywood, and engineered wood product manufacturing; (3) other wood product manufacturing; and (4) paper manufacturing, as well as for the logging sector.[13] The survey asked all firms to what extent they had innovated and the general circumstances they face in deciding to pursue innovation and additional sets of question for firms that did report innovating during the period covered by the survey. We use this data to examine the characteristics of cooperative R&D for Canadian forest products firms.[14]

THE CANADIAN FOREST PRODUCTS INDUSTRY

The forest products industry in Canada is a significant source of economic activity across Canada. In 2000, the industry employed 373,300 people, contributed \$20.8 billion to GDP, exported \$47.4 billion in goods, and accounted for 68% of Canada's trade surplus (Natural Resources Canada, 2001). It is divided into two manufacturing sectors, one producing pulp and paper and the other solid wood products. A third sector, the harvesting sector, provides logs to the two manufacturing sectors.

R&D in the Canadian Forest Products Industry

Studies on the nature of R&D in the Canadian forest products industry have found R&D expenditures to be low, both relative to other countries with forest products industries, as well as low compared to other sectors within the economy (Globerman *et al.*, 1999).[15] Ellefson and Ek (1996) offer several reasons why private firms in the forest products industry may not pursue R&D based on the nature of the forestry resource. They suggest that a long time lag between the research and the expected benefits, such as in silvicultural research aimed at improving tree yields or characteristics, are unlikely to attract private investment. They note that where resources are relatively abundant, the benefits of such research are unlikely to be significant which will also reduce the incentive to engage in such research. They also note that the public goods nature of many aspects of the forest resource (forest recreation, watershed issues, and wildlife) leads to market failure.[16] At the same time, however, growing awareness of the environmental impacts of timber harvesting, and a move towards incorporating environmental information into the product through certification, have all increased the emphasis on meeting new environmental regulations through research and innovation.

Globerman *et al.* (1999) examine several factors that affect the rate of innovation in the Canadian forest products industry. A number of different market factors all reduce the incentives for forest product manufacturers to engage in R&D: cyclical markets reduce the availability of assured funding; a lack of close contact with consumers reduce opportunities to customize products; and inelastic demand reduces the benefits from successful cost-cutting innovation. Production factors also influence the relative opportunities firms face at a more regional level: such as the availability of low-cost inputs; raw material variability; location; and access to trained personnel. Canadian firms also tend to be small relative to their global competitors, and the Canadian forest products industry remains relatively unconcentrated (Globerman, 1999, pp. 29, 30).

One of the problems in the forest products industry is that many technical innovations become embodied in the equipment, which then becomes available to a firm's competitors. The vice-president and general manager of a new pulp mill describes how the consultants that designed their mill are in the process of designing a mill for another firm:

> 'It's one of the ironies of the global marketplace, said Jerry Fenner...You can't hold back your technology. Because we have started up very successfully and are producing very high quality pulp, Simons [the consultant] will be given more business. But it means Simons will be more successful because they are working for our competitors...We literally have no secrets...You end up giving away your technology to anyone who wants it'. Williamson (1994)

Statistics Canada (2001), in its survey of Canadian manufacturers, asked about possible obstacles to innovation and found that the two most frequently cited obstacles by forest products firms were the high cost of development and the inability to devote staff to projects on an on-going basis because of production requirements.[17] The survey also asked firms what were the objectives of innovation, offering 11 broad categories including meeting regulatory requirements, improving process efficiency, and introducing new products. In general, forest product manufacturers that innovated chose those reasons related to production methods and process efficiency, with the need to increase production capacity, reduce materials consumption, and reduces energy consumption given as the most relevant reasons.

Our theoretical analyses suggest that a sector such as the Canadian forest sector, characterized by a high degree of competition and technology spillovers is likely to see low levels of R&D. The limited opportunities for product diversification will cause a higher focus on process rather than product innovation. Firms will tend to invest in R&D to find technological solutions to specific problems they face (so spillover would be minimized). The small size of firms suggests that firms may seek to join R&D consortia to provide access to technological expertise and to reduce their costs. Given the diversity of raw materials that the industry uses in Canada, and the unique technological problems it creates in different regions, the theory predicts the emergence of regional cooperative ventures. National cooperative ventures would tend to focus on technological solutions to problems generated by national regulation or common problems of foreign market access. We have found, however, that national industry-wide consortia are the dominant form of cooperation in the sector.

Governments (who own more than 95% of the commercial forest in Canada) play an important role in funding R&D in the sector and may induce cooperative R&D by paying a relatively high share of its costs (thus making participation in R&D consortia attractive despite the high degree of spillover and the negative impact on product prices resulting from intensified competition). It is possible that the important role played by the Federal Government in Canada in establishing and funding cooperative R&D led to the evolution of country-wide consortia. Our findings suggest that this required some of the consortia to accommodate regional interests through their governance systems. In the following sections we explore the extent of cooperative R&D and its foci in the different segments of the industry.

The Canadian Pulp and Paper Sector

The paper manufacturing sector produces both pulp and paper. Pulp is sold to other firms that then manufacture it into paper products.[18] Canada produced 31.8 million tonnes of pulp and paper in 2000; of that, 16.7 million tonnes were paper, 11.1 million tonnes were market pulp, and 4.0 million tonnes were paperboard. Total shipments were slightly lower at 31.5 million tonnes; of that, 5.0 million tonnes went into the domestic market and total export shipments were 26.5 million tonnes. The most important export markets were the USA, with 16.6 million tonnes, followed by 4.7 million tonnes in shipments to the Pacific Rim (Asia plus Japan), with the remainder exported to Europe, Oceania, and other regions (Pulp and Paper Products Council). Canada's share of the world pulp capacity in 1999 was approximately 15%, but it was the world's largest supplier of market pulp with 28% of global capacity (Pulp and Paper Products Council, 2000a, b). Canada has 24% of the world newsprint capacity and is also the world's largest exporter of newsprint (Natural Resources Canada, 2001).

The products in the sector are largely commodity products. Canadian producers, however, enjoyed an advantage in newsprint as the fibre used in Canada is longer and stronger. However, technological innovations have reduced that advantage as Canadian producers face increasing competition from lower cost producers in Asia and the US South. Globally, new plants have become increasingly larger in size in order to take advantage of economies of scale in production. The overall trend within the industry has been towards mergers and acquisitions as firms seek to increase their size to better compete in the global marketplace by finding economies of scale in distribution and marketing. Expansion of capacity in Canada was limited in recent years and in relative terms Canadian firms in the sector are small. The sector is capital-intensive and technologies are largely supplied by few foreign large equipment manufacturers. The industry is facing significant costly constraints with respect to end-pipe emissions. These constraints require technological solutions.

The survey on innovation reported that 60.9% of all pulp and paper firms had carried out R&D activities, slightly greater than the reported frequency for all manufacturers (58.6%). For pulp and paper firms that had carried out innovation the most frequently cited internal sources of information were: management staff at 77.1%; production staff with 75.1%; marketing staff with 74.9%; and followed by internal R&D departments with 53.3%. Suppliers of equipment were the major external sources of information for those firms (73.6%), followed by clients (66.8%).[19]

Cooperative R&D in the pulp and paper sector. In the survey of Canadian manufacturing enterprises 39.0% of the firms that innovated in the pulp and paper sector reported entering into cooperative arrangements compared to the rate for all manufacturers of 33.0%.[20] The most frequently reported reason to enter into cooperative arrangements was accessing R&D (63.5%) followed by the desire to access critical expertise (57.1%) and the need to access new markets (45.9%).[21] Reasons such as sharing costs, reducing risk, and developing prototypes were cited less frequently. Paper manufactures indicated that they were more likely to collaborate with clients, but not with competitors.[22]

The Form of Cooperation

Within the pulp and paper industry, there are a number of different cooperative research arrangements in place. The dominant cooperative organization is a nation-wide independent R&D consortium—Paprican, a cooperative research institute supported principally by industry with minor contributions from government. Overall, in 1995 Paprican funding accounted for 30.3% of all funding of R&D sector in the pulp and paper sector.[23] There are also short-term contracts between equipment suppliers and manufacturers, and manufacturers and independent research organizations with expertise in pulp and paper (such as the Alberta Research Council). There are also several university–industry research consortia. The university–industry consortia are organized around different themes reflecting largely the interest or specialty of entrepreneurial researchers in the universities and/or incentives of government program funding.

Paprican. The organization roots date back to a Federal laboratory established at McGill University in 1913 to investigate forest products. It became a three-way partnership between the federal government, industry, and the university in 1925 (Hayter, 1987). Today it has facilities at two universities, an educational program at another, and eastern and western laboratories. It now operates as a not-for profit corporation. Its members account for 80–85% of all pulp and paper production in Canada.

Paprican engages in pre-competitive and applied research as well as developmental research that is too expensive to be carried out by individual firms (Hayter, 1987). Paprican has several different research programs: fibre supply and quality; mechanical pulping; chemical pulping; papermaking and product performance. The strategic objectives of Paprican are to: reduce emissions (through progressive system closure); reduce fibre and energy costs; investigate the interrelationship between fibre and pulp properties; enhance product properties, and improve product quality (in terms of greater predictability and more uniformity in products). The organization's focus is 'on delivering short and long-term value to their members'. It conducts research ranging from fundamental research to applied research for both global and regional companies and provides a number of different ways in which members can interact with the consortium (Paprican, 2001).

Over time there has been a shift away from fundamental science with the organization devoting more of its resources to technology transfer and acting as a system integrator by applying the results of basic science taking place in universities to the technical needs of member companies (Hayter, 1987). It is also serving an intelligence function for the industry 'pushing technology out into the industry' (McDonald, 2001). This role has increased as individual in-house R&D has been scaled back and the absorptive capacity of companies declined.

The research Paprican undertakes focuses largely on technology platforms and precompetitive research. The organization has found little support from its members for product research designed to explore new opportunities to sell products or enhance the value of existing products. Members, however, favor investments in cost-cutting despite the recognition within Paprican that the opportunities to add value through cost-cutting are limited since the cost curve is becoming flatter and 'there is no real advantage from being in the lowest quartile' (Wright as quoted in Rodden, 2000). The emphasis on cost-cutting in a large consortium of firms facing inelastic demand is surprising, especially since many of the technologies are not specific to Canadian conditions and spill over to international competitors. Indeed the management of Paprican sees its future in research emphasizing product differentiation and customization, focusing on the enhancement of special qualities of Canadian fibres.

Protecting information. Smaller inventions (i.e. inventions worth less than $100,000) might be licensed out to non-members but Paprican will either give lead-time to its member companies (so member companies enjoy an advantage of first movers), or charge royalties with differentiated prices for member and non-member firms. The benefits to individual members from participating in a project is immediate access to the innovation and assistance in technology transfer to their own operations; non-participating members get more general knowledge that may not be as applicable to their specific mills.

Table 1. Paprican funding for Selected Years (in $ millions)

	1979	1986	1995	2000
Paprican	10.0	20.7	33.4	35.8

Sources: Solandt (1979), Science Council (1992), Globerman *et al*. (1999), and Paprican Annual Reports.

Funding. Table 1 below shows historic funding for Paprican for selected years since it was privatized 22 years ago.

There are two categories of membership, regular and one for allied members which includes suppliers. Allied members join for specific research; they may supply cash, grant-in-aid, equipment, and/or perform some of the work. Membership gives them access to the results of the research project. Regular members pay a fee assessed on the volume of production. The majority of Paprican's budget is funded by regular members' fees. In 2000, approximately 80% of Paprican's funding came from member fees; 15% from contracts and grants-in-aid; and 5% from governments (mainly federal) (MacDonald, 2001).[24] Proprietary research currently accounts for a very small percentage of revenues and expenditures, but there has been a demand from members for more investment in proprietary research and Paprican is planning to increase it in the future. Paprican recently completed the construction of small-scale paper and pulp machines at their facilities that should permit them to engage in such research.[25]

Paprican has recently revised its fee structure, allowing firms more influence on the research agenda. Value delivery is a new area/categorization of research activities, developed within the past year. It is funded by a portion of the membership fees that firms can earmark for projects at Paprican in which they have a specific interest. Companies can use this portion to take a research project further or use it for technology transfer (customizing results for their mill or company). The portion of funds under value delivery accounts for approximately 20% of all funding. The organization has also decided to seek partners internationally. MacDonald (2001) notes that technology does not stop at the borders since international firms with operations in Canada may transfer any expertise gained within the company at a Canadian operation to other operations outside of Canada. Paprican is therefore promoting international memberships.

The mechanical wood-pulp network. The Network Centres of Excellence (NCE) program was launched by the federal government over a decade ago aimed at providing seed funding to facilitate research in areas that are expected to, in future, provide economic benefits to Canadians and improve their quality of life. The networks consist of linkages between researchers at different academic institutions and others, each organized around a particular topic and given a commitment of federal funding over several years.

Established in 1990, one of the first NCEs was in the area of mechanical pulping in recognition of its economic importance to the Canadian forest products industry (Canada is the world's leading producer of mechanical pulps). The Mechanical Wood-Pulp Network is unusual in that it is industry led. The head of Paprican, which also provides the administrative support for the network, chairs it. It spans researchers at a number of different universities across Canada as well as pulp and paper companies, suppliers, and provincial government agencies. The network is focused on improving the characteristics of mechanical pulp and keeping the Canadian pulp and paper industry very competitive in an environment of increasing competition, with a focus on research that derives the maximum value from fibre found within Canada and provides the most benefit to domestic suppliers.

The most recent budget for the network was an estimated $7 million based on cash and in-kind contributions, of which slightly more than $2 million consisted of cash with the remainder in-kind contributions of facilities, equipment, and personnel. The federal government supplied nearly all of the funds, while Paprican supplied no funds but $4.6 million in in-kind contributions. Contributions from pulp and paper firms, suppliers, and provincial agencies were relatively minor and accounted for the balance (Mechanical Wood-Pulp Network, 2000). The consortium allowed Paprican to use government funding to access university expertise and focus a cooperative effort on an area of high priority to its members.

Observations. The relative small size of Canadian pulp and paper companies and their relative low technological resources explain the high share of cooperative R&D out of all R&D in the sector. The high rates of technology spillover within and outside the country call for internalization through an inclusive consortium with a large membership. The consortium can also serve to coordinate technological responses to the regulatory system (in particular environmental regulation). The emphasis of members on cost-cutting innovations reflects competitive pressures felt from new low-cost producers outside the country. A focus on Canadian specific technological improvements may reduce the rate of spillover. However, much of the value added through cost-cutting innovations is eventually captured by customers. Shifting the research agenda toward competitive product innovation, however, may create competitive advantages to some members and not others. Perceived inequities in cost and benefit distribution are typical causes for consortia failure and defection of members. An appropriate governance system can resolve tensions resulting from perceived inequities. Paprican has adjusted its decision processes, allowing members to vote with part of their membership fees for the research program they want.

The advantages of membership stemming from funding precompetitive research are derived from access to new information and customization services provided by the consortium. Indeed, for firms with little technological capabilities of their own, membership in Paprican offers access to expertise and technological intelligence. Though government's share in funding operating expenses of Paprican is insignificant, the government played an important role in funding its facilities. The NCE program provided Paprican with additional opportunities to use government funding and university expertise to promote research that is likely to contribute to the competitiveness of Canadian companies.

The Solid Wood Sector

The solid wood manufacturing sector consists of two principal sub-sectors in terms of production and shipments in terms of both volumes and values. The first sub-sector contains sawmills, mainly producing softwood lumber used for residential construction and renovation.[26] The second sub-sector contains producers that manufacture panelboard (plywood and composite panel products such as Oriented Strandboard (OSB)) and engineered wood products (composite wood products that substitute for large dimensional lumber).

Lumber products are commodities that have changed little over the years. They face increasing competition from other building products (such as steel studs) and engineered wood products. Lumber manufacturing has become more automated as firms have adopted computer software and new technology to improve processing efficiency and by emphasizing cost competitiveness. Technology increasingly permits firms to use wood that was once considered inferior or too small to produce lumber or substitute products (Natural Resources Canada, 2000, p. 43). The lumber market is highly competitive; the largest Canadian firm in 2000 accounted for 8.1% of Canadian production, while the top 30 lumber producers accounted for 81.5% of all Canadian production (Taylor, 2001).

The levels of investment in R&D are relatively low and firms derive much of their technological innovation from external sources. The survey on innovation reported that 42.9% of all sawmills and 49.1% of all engineered wood products firms had carried out R&D activities, less than that reported for all manufacturing firms (58.6%). Of the sawmills that had innovated, 24.6% of the firms cited internal R&D staff as a source of information, compared to 38.5% of engineered wood firms. Suppliers of equipment were the major external sources of information for sawmills and engineered wood products firms (76.9 and 80.2%, respectively) while clients were the next most frequent source cited (44.4 and 44.5%, respectively).[27]

Cooperative R&D in the Solid Wood Sector

Almost the entire R&D conducted in the solid wood products sector is cooperative R&D of one form or another (Binkley and Forgacs, 1997). The dominant cooperative is Forintek, a nationwide consortium accounting for 91% of all R&D expenditures in the solid wood sector in 1995.[28] Some of the cooperation takes place through short-term contracts between manufacturers and suppliers and some through various industry associations that exist within Canada as well as at independent research institutes such as the Alberta Research Council. An example of association-led R&D cooperation is the Zarai project that involved a partnership between lumber producers on the BC Coast, the regional trade association representing them, and the University of British Columbia. The consortia was formed to deal with the problem regional producers had selling wood products into the Japanese market.[29] Through the Coast Forest Lumber Association (CFLA), several members pursued a cooperative program to create a brand for the product and to conduct research into the design and structural properties of the wood which preliminary evidence had suggested was undervalued. The research was organized in two stages, with the initial members branding their wood in the first stage; the second stage consisted of additional research into the properties of the product to promote the recognition of its higher design and structural values by Japanese standard-setting bodies. Recently announced revisions to these standards will allow other member firms producing a similar product the same opportunity to sell into the Japanese market (although they cannot brand their wood). Funding for the program was received mainly from the provincial government, which contributed 100% of the research funds and 30% of the market promotion funds.[30] Other examples of association-led work include research conducted by Canply, the trade association for Canadian plywood makers that operates a small research facility in BC as well as participating in research done at other institutions. The Alberta Research Council (ARC) has a research alliance with Forintek enabling the two organizations to pool resources and expertise in the particular area of OSB manufacturing. In addition, ARC conducts its own research under contract to forest companies in Alberta on issues of interest to them.

The survey indicated that out of all sawmills that reported technological innovation, 22.1% reported entering into cooperative arrangements. In the engineered wood sub-sector 40.1% of all innovators entered into cooperative arrangements. The motive most frequently cited by all sawmills for entering cooperative arrangements was accessing new markets (48.8%), followed by accessing R&D (45.0%) and accessing critical expertise (42.8%). The most frequently cited motive for engineered wood product firms was accessing R&D (69.3%), followed by prototype development (51.9%) and accessing critical expertise (51.7%).[31]

Forintek. The organization was originally made up of two federally funded laboratories, the Western Forest Products Laboratory (established at the University of British Columbia to conduct wartime research into the use of spruce in aircraft construction) and the Eastern Forest Products Laboratory. The two separate labs were privatized in the 1970s and merged into one organization (Hayter, 1987). Forintek operates now as a not-for profit corporation.

Forintek conducts research in four main areas: resource assessment, which focuses on the relationship between raw material and product attributes; market access, which involves construction codes and the suitability of wood products and lumber standards; lumber manufacturing, which focuses on production efficiency and improving the value of finished products, and composites manufacturing. The overall focus is on technological advancement to maintain the competitiveness of wood products and encourage their use. The historic focus has been on cost reduction and cost minimization and remains the most important part of the research effort. The organization is working on developing the idea of adding value to improve prices rather than merely focusing on cost reduction. The emphasis is on a generic improvement as opposed to proprietary product development and differentiation.

There is a national research council with a strategic planning committee chaired by the CEO that set the guidelines for fund allocation among research areas. All project ideas that are brought forward to a national technical advisory committee are voted on by the members. Only members (companies and governments but not Forintek personnel) can vote. Research ideas originate from a variety of sources, including market intelligence, conferences, mill visits, and member companies. For a project to move forward it must get membership support and find a project liaison (a champion).

Forintek generally adopts research ideas that are focused on Canadian species and innovation that helps Canadian firms to meet foreign regulations or help change foreign regulations to increase market access for Canadian products.

Protecting information. Members have a royalty-free right to use research results (but not the right to sell the results). All knowledge/technology developed is owned by Forintek (even when federal government funds are used). The organization has a choice in how it chooses to release information. Much of the information developed is protected. For example, Forintek developed a chemical formulation to prevent sapstain and considered whether to license it to a supplier or to patent it. They decided to license it since licensing would reveal less information. If there is no interest among members in the innovation, Forintek seeks to patent it and looks for partners interested in fuller development and commercialization of the innovation. Members always get the first opportunity at using the information developed through Forintek's research.

Funding sources and expenditures. Table 2 shows the historic funding levels of Forintek for selected years since it was privatized twenty-two years ago.

Membership fees for primary producers are based on their volume of production and differ between lumber producers and panel producers: 25 cents per thousand board feet for lumber producers or the solid wood equivalent (SWE) of 9 cents per thousand square feet for panel producers.[32] Membership is open to firms who must include all their mills. There are three different categories of members:

1. Primary producers, with a fee based on their production;
2. Secondary producers, with a fee based on value (measured by their sales and meant to correspond to fee charges primary); and
3. Associate, for suppliers (chemicals, equipment) pay fees based on their Canadian sales and participate in specific research projects.

Industry members through fees, contributions, and contracts cover 42% of the budget, the federal government 30%, and licensing accounts for another 4%, with the remainder coming from provincial governments. Contracts accounted for $8 million or approximately 1/3 of all revenues in 2000.

Table 2. Forintek Funding for Selected Years (in $ millions)

	1979	1986	1995	2000
Forintek	8.8	14.0	14.5	21.8

Sources: Solandt (1979), Science Council (1992), Globerman *et al.* (1999), Forintek Annual Reports.

Over the years there has been a shift in funding sources. In 1984, the industry accounted for only 25% of the revenues, with the federal government contributing 50% and the provinces the remaining 25% (Science Council, 1987). Forintek revised suppliers' fees downwards several years ago so that more would participate in its activities. Contract fees paid by member companies have increased significantly as a source of revenue in the past few years. Forintek has not created any kind of 'cafeteria style' membership fee, in which companies direct their money to specific areas, although a few companies have floated this idea in the past 2 years. Members, however, can influence the agenda through contracts and contributions. Forintek is making an effort at present to expand its membership outside of Canada. The target at present is only bringing in subsidiaries of Canadian headquartered companies that have mills in the US.

Observations. A highly competitive environment, undifferentiated products, inelastic demand and small enterprises explain generally low levels of R&D investment in the solid wood sector. Diversity of species requires some adjustment in otherwise standard (slow changing) technologies to adapt to local conditions. Suppliers of equipment and raw materials (e.g. chemicals) are natural partners in customization of technologies. This is achieved through short-term narrowly focused contracts. The incentives for development of more generic cost-cutting technologies are relatively low since the benefits are likely to be captured by customers. Spillover of technological innovations are high and incentives to join a consortium are small. Large government funding of the national consortium (Forintek), however, changes the cost benefit ratio to members who generally lack technological expertise and are provided access to research and development services and technological expertise through the consortium. Indeed the 'option value' of such access is paramount among the benefits that members see in joining the consortium. Market opening work is largely a 'public good' that members may not support except with governments paying a large share of the costs. The use of registered trademarks by members in a cooperative project is one way in which they can reduce free-riding and encourage participation.

The shift that Forintek sought to rely more on fees from contracts with specific members presents a puzzle. Why should firms join a consortium that benefits some (those who contract Forintek) and not others? Indeed, why do not these inequities in benefit distribution lead to significant defection of members who do not enter into these contracts with Forintek? This puzzle is resolved, however, by recognizing that members buy potential R&D capability to be used when they need it. The fees cover the 'option value' while contract fees cover the use of the joint R&D capability. The phenomena of private contracting and proprietary research may also represent the independent existence of Forintek as an organization that pursues in part organizational objectives of its own (e.g. survival and expansion).

The Harvesting Sector

The harvesting sector is made up primarily of small firms that conduct harvesting and road-building operations, producing logs for both the solid wood and pulp and paper sector and sold primarily into the domestic market. In 1997, the most recent year for which detailed numbers are available, 187.8 million m^3 were harvested from 235 million hectares of productive forest across Canada. Shipment values were $12.3 billion. In terms of shipment values, 69% were sawlogs and bolts shipped to sawmills, planing mills, and shake and shingle mills, and 13% consisting of pulpwood going to pulp and paper mills. Provincial Crown lands supplied almost 80% of production, and private land accounted for the balance. Canada supplies 5% of the total world production and 1/4 of North American production with 10% of the world's forests (Simard, 1999).

Over time, there has been a shift away from integrated firms operating their own logging divisions to contracting out logging to independent operators (who may conduct operations for more than one company). The operators rely on suppliers for their machinery, which they purchase and may then customize. Local conditions predominate. Contractors tend to be small relative to the overall market; the largest contractor in Canada logs 800,000 m^3 annually in BC (where contractors tend to be larger than elsewhere in Canada), or less than 2% of the annual provincial harvest (Crosby, 2001), and in 1997, small contractors accounted for over 44% of shipment values (Simard, 1999).

The harvesting sector within Canada encompasses both the logging and transportation of logs to processing facilities. Governments impose strict regulatory requirements on forest products firms leasing government land. Silvicultural research from an industrial perspective has in the past typically dealt with the establishment of trees under different growing conditions and the response of tree species to various silvicultural treatments involving different harvesting techniques. Increasingly, public concern over the environmental impact of forest operations means that more attention is being paid to environmental protection and the protection of wildlife and habitat (Simard, 1999).

Cooperative R&D in the harvesting sector. As indicated earlier, while forestry research takes place at universities and within government across Canada, most of it is focused on environmental aspects and basic forest science. Given government ownership and the public good nature of many of the forest benefits it is not surprising that governments have significant involvement in two research cooperatives which focus on the 'upstream' of the forest product industry (i.e. silviculture)—FERIC and the Sustainable Forest Management Network (SFM). FERIC is a nationwide R&D consortium involving industry and governments. It is the only significant source of research into the commercial aspects of logging systems, transportation (including road-building), and commercial applications of silvicultural techniques.[33] The SFM network is dominated by university researchers with partners from various forest stakeholders, including industry, government, community groups and aboriginal communities. The research focuses on sustaining the boreal forests of Canada.

The survey of Canadian industries indicated that out of all logging firms that reported technological innovation, 28.4% reported entering into cooperative arrangements. The motive most frequently cited by firms for entering cooperative arrangements was sharing costs (53.6%), followed by accessing R&D (46.5%) and accessing critical expertise (37.4%).[34]

FERIC. The organization was formed through the amalgamation of part of the logging division of Paprican and the corresponding division of the Eastern Forest Products Laboratory in the 1970s (Hayter, 1987, p. 36) and now operates as a not-for profit corporation. The organization's research mission has been described as being site-specific and focused on developmental activities and in promoting best use practices (Hayter, 1987). FERIC groups its research into three areas: improving the cost-effectiveness of forestry operations; optimizing work and product quality; and 'respecting' (protecting) the forest environment (FERIC, 2000).

There has been a shift in FERIC's operations over the past 5 years to an emphasis on technology transfer. This was in response to a loss of members who were not interested in the long-term benefits that improvements in silviculture offer. To retain members, FERIC conducts cost benefit analyses for members of their participation in FERIC activities. Their calculations typically show ratios of 1:5 and 1:10 return on investment (membership fees).

FERIC emphasizes regional balance and representation in choosing its projects. It therefore considers projects that may be very important for only a few members. It also provides a voice to regional preferences through its committee structure. Projects can be proposed by members (including governments), researchers, or associations. Part of the project identification is the site location. Projects need the active support of some industrial members (champion). Government influences the research agenda by funding entirely some projects where there is no industry interest.

Protecting information. There are two categories of research reports: one restricted to members and a second that is non-restricted (free to members with some cost to non-members). Restricted information is reviewed after 2 years. If it provides a strategic advantage to members it remains restricted; otherwise, it is released to the public. FERIC research outputs are often visible and non-members enjoy externalities from its research. FERIC is trying to reduce spillover to non-members but is constrained in part by the obligations entailed in receiving government funding and the difficulty in patenting new practices.

Funding. Table 3 shows the historic funding for FERIC for selected years since it was privatized 22 years ago.

Table 3. FERIC Funding for Selected Years (in $ millions)

	1979	1986	1995	2000
FERIC	2.0	4.9	7.6	9.0

Sources: Solandt (1979), Science Council (1992), Globerman *et al.* (1999), FERIC, Annual Reports.

The organization is principally made up of industrial members that utilize the wood (covering 70% of all industrial wood harvested in Canada) and government members (most provincial forest ministries). The industrial members include solid wood producers and pulp and paper firms as well as some contractors and other organizations with an interest in forest management. All of the major companies are members but members can elect to enroll only some of their divisions. Industrial members are assessed on wood consumption at their own mills (4.3 cents per m^3) without any distinction between different types of end use. Fifty percent of FERIC's revenues currently are received from the industry; 10% from the provinces; 20% from the federal government and the remainder from grants and contracts.

This represents a shift away from government funding to higher reliance on industrial members.[35] The traditional funding model was based on one rate for industrial memberships, which entitled members to the entire program. Some members are now requesting to buy portions of the research or partial programs (as opposed to the all-in or all-out) and some are also asking about membership by region. Funding continues to be problematic; in 2000, additional government funding was critical in retaining some industrial members and helped attract several new members (FERIC, 2000). The funds are spent approximately half on research and half on communications (a negligible amount, about 2%, is spent on contract work).

The sustainable forest management network. The network was established as part of the NCE program. Its annual budget is more than $7 million. Governments fund about 58% of the budget and industry about 21%. Its research programs organized along three themes (or legacies): understanding disturbance, strategies for sustainable forest management, and impact minimization. While the research program reflects largely the specific interests of university researchers, the objectives of the program and its general priorities are strongly influenced by the industrial and government partners. The major output of the organization is basic science and applied science. Its major challenge is technology transfer.

Observations. R&D in the forestry sector is quite distinct from the R&D in the manufacturing sectors of the forest industry in several ways: (1) it has a higher 'basic science' content; (2) the knowledge generated is more regional and site specific; and (3) much of the benefits generated are long-term and less visible. These attributes of R&D indicate a larger role of governments in funding research to correct for market failures. The public nature of many innovations suggest also that industry may have an interest in participating in the research process only if it helps transfer specific knowledge. This creates two opposing forces that affect cooperation. Government funding promotes national inclusive consortium while the desire of individual members is to promote exclusive regionally centred consortia. FERIC resolves this conflict by a national structure that allows economies to scale and scope in research, the pooling of expertise, with strong regional influences on its research agenda. The shift of emphasis to technology transfer and customization are a reflection of the difficulty that the organization experienced in protecting its intellectual properties.

The emergence of the Sustainable Forest Management network is largely due to long-term government financing and the industry's quest for legitimacy through a sustainable development path. Participation in the NCE by industry is part of its manifestation of social responsibility rather than a means for finding immediate solutions to urgent problems. Not surprisingly long-term objectives characterizing basic science dominated output of the network during its first phase. A characteristic feature of cooperative R&D involving universities and industry is the tension between the desire of academics to focus on basic research and the pressure of industrial partners for commercial applications.

DISCUSSION AND CONCLUSIONS

Our case study has provided support to most of our hypotheses. An important factor in the emergence of R&D consortia was access to expertise and R&D services which was not otherwise available to Canadian forest sector firms because of their relatively small size. The high degree of spillovers motivated the emergence of national inclusive research consortia with the participation of almost all major firms in the industry.[36] Governments played an important role in the formation and funding of the research consortia. The share of government in funding the cooperative ventures was higher in the forestry sector where an important part of the R&D is the generation of basic scientific information, where benefits are uncertain and are realized in the distant future and 'free-riding' is facilitated by difficulties in protecting intellectual properties and easy imitation of innovations. In the pulp and paper sector, higher levels of capital intensity and national regulation, which require technological solutions, increase the incentives for firms to collaborate despite the absence of similar high levels of government support.

We have found few instances of long-term or relational contracts to perform joint R&D. In most cases cooperation outside national consortia was between suppliers of equipment and firms mostly through short-term contracts. Contracts with suppliers of equipment or other inputs focused on problems specific to their customers. The high degree of competition in the three sectors meant low levels of trust and reliance on independent organizations to perform the cooperative R&D. Surprisingly and in contradiction to the hypothesis cost-cutting was a high priority to members even in areas where Canadian manufacturers as a group have a significant impact on the international market and cost-cutting would lead to reduced prices. This emphasis on cost-cutting reflects the eroding competitive position of Canadian manufacturers. The emphasis on research results specific to Canadian conditions helped however to contain spill-overs. Members also rely on the consortia to provide technological intelligence and help firms find technological solutions for their cost competitiveness challenges. Comparisons of the extent of cooperative R&D among the three sectors of the industry reveals that the higher the technological intensity of a sector (or sub-sector) the higher the propensity of firms to join consortia. We also have found that the more technologically sophisticated companies were more likely to join. This may reflect the fact that to enjoy the benefit of the cooperation firms must have a threshold level of technological absorption capacity. Those with more technological abilities can adopt innovations faster.

Our case study also highlights the importance of governance structure in motivating participation. All three organizations were attuned to the diversity of needs of their members and developed strategies to meet those needs. Paprican allowed its members to influence the research agenda by 'voting' with a portion of their membership fees for specific projects. Forintek expanded its members initiated and funded projects program. FERIC developed agendas of research adapted to the needs of different regions.

We also discovered some principal-agency tensions: consortia develop their own objectives (survival and growth) which are independent of their members. All three organizations are facing demands from their members to reduce the cost of participating in the consortia while still maintaining access to research programs of interest. Indeed all of the consortia have sought profit-making opportunities outside the strict boundaries of the joint goals of their members. These ventures, however, were seen as means to decreasing the financial burdens on members and ensuring the stability of the consortia. Indeed, if an important motive of membership in consortia is the 'option' to access expertise and services, finding 'private' sources of funding for the consortium reduces the cost of buying the option.

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NOTES

1. They have four cases in their model: R&D competition, in which firms decide on their R&D unilaterally; R&D cartelization, where firms coordinate their R&D expenditures but do not share information; RJV competition, in which firms do not coordinate their R&D expenditures but do share information; and RJV cartelization, where firms coordinate R&D expenditures and share information fully. It is in the latter case where firm profits and consumer surplus are maximized.

2. Anderson describes several different activities under each of these three modes and also notes that there is a great degree of overlap and interplay between these three modes. Under research-oriented cooperation, there is university-based cooperation; university–industry–government, cooperative R&D, R&D corporations, venture capital, and equity. Under technology-oriented there is technology sharing, cooperative production, customer–supplier agreements, and licensing. Under market oriented there is licensing as well, distribution, promotion/marketing, service maintenance, and regulatory assistance.
3. In some case these are due to network externalities, where the value of a good is derived from how widely it is used. One example would be a standard operating system for computer software.
4. An example of firms forming a cooperative research venture for this purpose was the case known as the Smog Conspiracy in which a group of carmakers formed a research joint venture to develop and cross-license royalty free emission controls in the 1950s. So little progress was made that the City of Los Angeles approached the US government to bring an antitrust suit against the carmakers, arguing that they were using the research venture to suppress rather than encourage innovation (Murphy, 1991).
5. An example of long-term contractual research arrangement would be contracts the US Department of Defense enters into with private firms to conduct research on new weapons systems (Goel, 1999).
6. They define trust as confidence in others' goodwill as opposed to confidence in one's expectations.
7. Link and Bauer (1989) identify seven different types of research consortia operating in the US based on the participants and nature of the research: (1) industry consortia conducting long-term R&D; (2) project-specific industry joint ventures; (3) research corporations with their own research facilities; (4) trade association/research foundations; (5) research conducted to meet EPA regulations; (6) university-based research centers; and (7) company-funded independent research institutes.
8. They restrict their examination to US federal government laboratories and RJV registered with the US government.
9. Formally, the payoffs from R&D output exhibit diminishing rate of return as the number of firms increases because member firms face downward sloping demand curves, and revenues rise at a diminishing rate as membership increases and the output of the R&D (which increases at a slower rate) is spread across more firms. At the same time, monitoring costs increase at an increasing rate with the number of firms.
10. The government has the ability to do this through several means including: formal auditing procedures; the possibility of reprisal by either legal means or the future exclusion of non-compliant members; and lending long-term stability and structure to the RJV.
11. Here uncertainty refers to commercial uncertainty (whether or not a technology will be commercially successful) and dynamic uncertainty (whether the technology will remain valuable in a changing environment).
12. We interviewed officials at each of the three research institutes, as well as academics involved in research consortia and industry participants.
13. The data was provided through funding by Industry Canada, Natural Resources Canada, and the National Research council of Canada and is available on request from Statistics Canada. Logging and forestry data is being compiled and is only available on a limited basis at the time this article was written.
14. The survey is based on a series of questions that either asks for agreement with a statement or the relevance of a particular factor. As such, it gives the frequency or the importance attached to various questions, but does not provide any quantitative measures of innovation or R&D activity in any of these sectors.
15. Watts and Kozak (2000, p. 8) estimated that in 1999, the most recent year for which detailed information is available, total funding of forestry research in Canada was approximately $345 million of which 49.2% was funded by governments.
16. Other factors they raise, such as the appropriability issue, costs of research, and uncertain returns have already been discussed.

17. Table 10.1: Problems and Obstacles That Firms Faced When They Innovated During the Period 1997–1999, Industry by Problems and Obstacles, Innovators in Manufacturing.
18. Pulp that is sold to unaffiliated firms is termed market pulp as opposed to that sold to another operation within the company.
19. Drawn from Table 24.1, Research and Development During the Period 1997–1999, Industry by R&D Activity, All Manufacturing. Also drawn from Table 8.1, Sources of Information That Contributed to Innovation During the Period, 1997–1999, Industry by Source of Information, Innovators in Manufacturing.
20. Table 14.1: Cooperative and Collaborative Arrangements During the Period, 1997–1999, Innovators in Manufacturing, All Firms.
21. Table 14.3: Cooperative and Collaborative Arrangements During the Period, 1997–1999, Innovators in Manufacturing, Reasons by all, Single and Multiple Location firms.
22. The one exception being paper manufacturers who were significantly less likely than others (including all manufacturers) to enter into cooperative arrangements with competitors.
23. This share is based on nominal R&D expenditures in paper and allied industries from Statistics Canada catalog 88-202-XPB and the Paprican budget for that year. Nominal R&D expenditures may exclude government contributions which are included in Paprican's budget.
24. In 1986, member fees accounted for 90% of the revenue, with the balance made up primarily of contract fees (Science Council, 1987).
25. One of the issues in pulp and paper is translating research results from the lab to the mill since the results may not hold on a larger scale. The construction of research facilities reduces the likelihood of this problem.
26. There are also hardwood manufacturers, whose products tend to be used for higher value uses such as flooring and furniture, and producers making specialty products for niche markets, but they are small relative to the softwood lumber industry.
27. Drawn from Table 24.1, Research and Development During the Period 1997–1999, Industry by R&D Activity, All Manufacturing. Also drawn from Table 8.1, Sources of Information That Contributed to Innovation During the Period, 1997–1999, Industry by Source of Information, Innovators in Manufacturing.
28. This is based on nominal R&D expenditures in wood industries from Statistics Canada catalog 88-202-XPB and the Forintek budget for that year. Nominal R&D expenditures may exclude government contributions which are included in Forintek's budget.
29. The product was green (non-dried) hemlock sold for traditional post-and-beam housing.
30. Funding was approximately $1.5 million annually.
31. Table 14.3: Cooperative and Collaborative Arrangements During the Period, 1997–1999, Innovators in Manufacturing, Reasons by all, Single and Multiple Location firms.
32. As of April 2, 2002.
33. Some silvicultural work is carried out jointly with Paprican and Forintek where there is an interest in how silvicultural techniques may modify fibre properties and the resulting products that can be derived from them.
34. Table 14.3: Cooperative and Collaborative Arrangements During the Period, 1997–1999, Innovators in Manufacturing Industries, Reasons by all, Single and Multiple Location Firms, as reported for Logging firms.
35. In 1987, members accounted for 44%, the federal government 36%, and contracts and grants 18% of the organization's revenues (Science Council, 1987).
36. In addition, suppliers of equipment were also encouraged to join in special categories of membership to provide their technological expertise to the cooperative venture. Their motive to join were largely the acquisition of Canadian client needs and the opportunities to enhance their sales. In most cases suppliers, however, could not formally participate in the decisions concerning research agendas.

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