INNOVATION AND COMMERCIALIZATION IN THE CANADIAN BIOPRODUCTS INDUSTRY

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ABSTRACT

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This thesis investigates the effects of resources and firm characteristics on the development of bioproducts in Canada. The analysis uses Statistics Canada's 2003 and 2006 Bioproducts Development Survey, the first national industrial biotechnology survey in the world. Since the industry is new and minimal firm-level information is available, little is known about firms' bioproduct development and production activities. The research develops a framework grounded in the resource-based theory of the firm to motivate product development decisions. A count data model estimating the effects of characteristics on innovation finds patents, strategic factors, R&D expenditures, collaborations, focus on bioproducts, and subsector among the significant factors. The firm's ability to capitalize on internal resources and obtain complementary external resources is becoming more important to innovative activity than market factors. These results have implications for technology development and commercialization strategies relevant to both firm managers and policy makers

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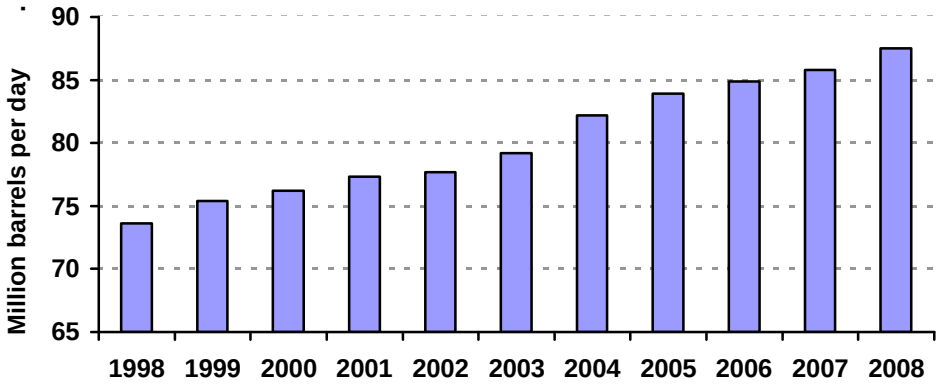
1 Introduction

1.1 Background

Industrial biotechnology is providing innovative solutions to mounting problems related to climate change, energy security, and sustainability. Arguably the greatest potential for these technologies is in delivering substitutes for petroleum based products, most notably fuel and energy. International demand for oil and petroleum products has continued to increase steadily over the past ten years (Figure 1.1), with consumption of transportation fuels driving this growth in many countries. This, coupled with the eventuality of exhausting non-renewable resource reserves, has spurred agents in various industries to find alternatives to existing energy and fuel sources. The bioproducts industry is developing novel products from biomass in response to current and anticipated demand for new and better products as well as rapid advancements in available technology.

Figure 1.1 World oil product demand 1998-2008



Source: International Energy Agency, Oil Market Reports (March 2008, December 2005, December 2002)
Note: 2008 demand is projected, as of March 11 2008.

Biomass is defined as "any type of organic material that is available on a renewable or recurring basis" (BIOCAP 2004, p.7) and derives from a variety of sources and sectors, most commonly agriculture and forestry but also aquaculture, municipal and organic wastes (Sparling et al. 2006). Products under development include consumer and industrial goods ranging from fuels to chemicals, plastics, pesticides, and catalysts. While the potential for such technologies has been acknowledged for some time, many of the technological developments and economic conditions necessary to bring this potential to fruition have occurred in recent years. In an industry with an exploratory focus and emphasis on discontinuous innovation, it is often the technology—not the consumer—that acts as a key driver (Veryzer 1998).

The bioproduct industry includes firms involved in development or production of products using renewable biomass. Although the global bioproduct industry is still emerging, Canada has the potential to become a major player. Statistics Canada's inaugural Bioproducts Development Survey for 2003 estimated that over 1,000 bioproducts were under development or in production by 232 firms across the nation (Sparling et al. 2006). Just three years later, the 2006 Bioproducts Development Survey indicates that 239 domestic firms are developing and producing nearly 1,500 products. Canada has a natural opportunity arising from an abundance of available biomass stocks, especially from agriculture and forestry sectors. The nation's strong biotechnology industry also provides fertile grounds for encouraging innovation and providing the necessary knowledge base and resources for industrial biotechnology development.

However, the industry is still young and both firms and government are trying to find their way.

While technology-driven industries have distinct opportunities, firms face hurdles in the form of technology development and acquisition, obtaining financing, and product regulation. Industrial and environmental biotechnology firms benefit from the existing infrastructure and knowledge networks of the greater biotechnology community but may also face unique opportunities and challenges associated with using biomass inputs and competing with existing petroleum products. Past research in other technology industries emphasizes the importance of collaborations and networks for sharing of intellectual property (Baumol 2003), valuation of products under development by the capital markets (Rzakhanov 2004), and the distinct roles of large and small firms in high technology industries (Guilhon 2004). Public/private partnerships between government and industry are common, having evolved to help mitigate some of these challenges for the purpose of increasing economic growth (Audretsch et al. 2002). This study will attempt to build on previous research by providing an in-depth analysis of the factors influencing innovation in the Canadian bioproduct industry overall, as well as the roles of individual firms within the industry.

1.2 Economic Problem

The bioproducts industry has an opportunity to provide large-scale private and societal benefits via novel products and alternatives to existing petroleum-based products in the

coming years. It may also serve as a new market for producers of biomass and facilitate the development of national infrastructure and human capital. Technology firms, agriculture, and consumers all stand to benefit from the expansion of this emerging industry. However, there is substantial uncertainty in the development process and it is not a simple task to generate estimates of production or costs given the many barriers to commercialization. In addition to familiar technology development hurdles, bioproduct firms face additional challenges associated with using biomass and achieving costs competitive with existing petroleum products (Wyman 2006). In many cases firms can convert internal production waste into valuable industrial and consumer products, a unique characteristic of bioproduct development. Further, the industry is diverse, using different inputs and producing different products, with widely varying firm resources and core competencies.

In light of these complications, the relationship between innovation and firm characteristics, allocation of resources, and external pressures is by no means clear. In a longer-term quest for profits, the firm must direct its efforts—and thus its valuable time and resources—towards a number of intermediate goals which may include conducting basic research, obtaining financing, securing intellectual property, developing prototypes, identifying suppliers, and a host of other activities. Which firm characteristics and consciously adopted strategies best facilitate innovation in the context of bioproducts remains unclear. Also uncertain are how current policy measures—strongly pursued due to the anticipated environmental and economic benefits expected in the long run from this industry—are affecting innovation levels. Addressing these issues would provide

valuable information for both firms and policy makers to help ensure the future growth and competitiveness of the industry. Such analysis would also help to identify weaknesses and gaps in current policy and regulation of the domestic industry, and serve to assist firm managers in improving their innovative activity and optimizing commercialization efforts.

1.3 Economic Research Problem

If decision makers are trying to develop programs to increase output/innovation, it is vital to understand the factors influencing innovative activity. Further, a broader view of the industry, how it is developing, and the factors conducive to success is valuable to firms trying to find their way in the new industry. The innovation literature provides limited context with which to analyze the firm's product development, particularly as bioproduct firms face unique challenges and constraints compared with other biotechnology or processing firms. While the biotechnology industry has been the subject of much research, it is comprised largely of companies developing products for the pharmaceutical market. Bioproduct firms by contrast face disparate incentives, a different regulatory structure and development process. The environmental issues surrounding bioproducts also lead to a different set of opportunities and challenges than those faced by a pharmaceutical biotechnology firm when it comes to decisions of product development, R&D investment, and financing decisions, among others.

Because of the newness of the industry, there is very little literature dealing with any of these topics. Research has been conducted looking at the technology development

process in general and areas such as R&D, government programs, collaborations, but results can vary depending on the industry studied (Audretsch et al. 2002). Thus far there has been no research analyzing innovation or technology development in the context of the bioproduct industry and its unique characteristics. Statistics Canada's Bioproduct Development Survey, conducted for survey years 2003 and 2006, is a first-of-its-kind and provides a wealth of information on industry and firm characteristics and activities. Determining factors influencing product development innovation for Canadian bioproduct firms would assist firms with their resource allocation decisions and strategic direction overall. Understanding specific factors affecting innovation would also equip decision makers with tools to better understand firms and set policies which will be of most practical value.

1.4 Purpose and Objectives

The purpose of this study is to identify and evaluate factors influencing bioproduct innovation by firms in Canada. Determining factors which relate to firm innovation will help to provide insight into challenges facing Canadian bioproduct firms. These insights will provide strategic direction for firms and policy makers to understand their role in the emerging sector and the development of innovative products and technologies.

The specific objectives of this thesis are:

1) To identify general characteristics of Canadian bioproducts firms and of the industry and important changes in recent years.

2) To review related literature on decision making in the context of innovation, identify and assess relevant criteria for undertaking product innovation, and use these to construct a conceptual framework for bioproduct innovation.
3) To evaluate factors conducive to innovation by developing an empirical model for assessing product innovation.
4) To determine implications for firms and develop recommendations for improving current bioproducts policy to better achieve environmental and economic policy goals.

1.5 Chapter Outlines

Chapter 1 provides background information to the topic and outlines the research problem and objectives. Chapter 2 provides important background on the state of bioproduct development in Canada and abroad, and outlines major pressures in the product development process. Chapter 3 provides descriptive statistics of the Canadian industry, and outlines changes occurring between 2003 and 2006. Chapter 4 reviews the literature and theory relating to innovation and industrial biotechnology development. Chapter 5 develops econometric models of product counts for 2003 and 2006 and discusses the results. Chapter 6 provides results and implications, and chapter 7 identifies limitations of this work and recommendations for future research.

2 Bioproducts and Bioproduct Development in Canada

2.1 Introduction

This chapter begins by defining bioproducts and introducing the bioproduct industry. Next, applications of bioproducts are discussed, as well as global and Canadian opportunities. Finally, the development process from basic research through to production is examined in the context of the firm as well as societal pressures and firm characteristics which may act to motive or hinder commercialization.

2.2 Bioproduct Overview

2.2.1 Bioproducts defined

There has not yet emerged one dominant definition of bioproducts despite increasing interest in the sector in recent years. Agriculture and Agri-Food Canada's definition, cited in their Agricultural Policy Framework of 2003, includes all products "developed from living organisms and their constituent parts that may replace or augment products derived from non-renewable resources". This study relies on Statistics Canada's Bioproduct Development Survey definition, which in 2003 included firms developing or producing "commercial or industrial product(s) (other than food, feed and medicines) made with biological or renewable agricultural, marine or forestry materials" (Statistics Canada 2004). This definition is made more explicit for the subsequent survey as follows:

> "Bioproducts are defined as products (other than food, feed, and medicines) made directly or indirectly with biological or renewable agricultural (plant or animal), marine or forestry biomass material. These products may be new or novel in nature or traditional products made of or with new or novel biomass."
>
> (Statistics Canada 2006, p2.)

The revised definition does not change the scope, but does plainly delineate the boundary between bioproducts and other products in terms of both inputs (biomass types) and outputs (bioproducts). It explicitly includes those products whose production uses agricultural, marine, and forestry biomass, but also leaves room for "new or novel biomass". Similarly, bioproducts excludes food and medicinal products which might already fall under pharmaceutical or other classifications, leaving primarily industrial products such as plastics and more environmentally-friendly versions of existing products such as chemicals and pesticides.

This leads to another difficulty with conceptualizing bioproducts—that there are differing terminologies to refer to essentially the same group of products. For instance, the overall technology is often referred to as environmental biotechnology or industrial biotechnology, as most of the products developed are intermediate goods used in industrial processes. While this does complicate the issue and make it more challenging to derive a uniform definition, it also shows that these technologies drive development of

a variety of goods for consumers and industry, from many different inputs and with benefits to several societal groups.

2.2.2 Role and importance of bioproducts

Bioproducts are providing opportunities for various sectors of the economy. Whether or not they prove to be the environmental panacea predicted by some, their development clearly has a greater impact than merely providing a product demanded by consumers. The industry has broad implications along social, economic and environmental dimensions (OECD 2004), providing solutions to both consumer-level demands and macro-level problems. One of the major economic opportunities for bioproducts is to replace existing petroleum and petroleum-derived industrial products such as fuels and plastics. Due to growing demand for oil and a finite supply looming on the horizon, there appears to be a increasing possibility of producing transportation fuels and energy from cellulosic biomass at a cost the market will bear. Environmental concerns such as sustainability and reduction of greenhouse gas emissions are societal drivers for the industry. At the micro level, some firms seek an outlet for by-products or waste from their primary production process, which can be costly to dispose of otherwise. The ability to develop by-products into secondary value-added products defrays disposal costs. In some cases there is an opportunity to develop entirely novel compounds and products. For instance, major chemical companies have produced biological enzymes which exceed the efficacy of traditional chemicals in processes used in pulp and paper production and clothing manufacture, while reducing pollution (UNU 2005). For reasons

such as sustainability, environmental impact, novel products, and improved product efficacy and safety, there is a great deal of incentive in the long term to move towards production of bio-based technologies.

One major concern is whether bioproducts can be competitive with existing products and processes. However, there will likely be some divergence in efficacy or efficiency in addition to the cost difference. In some instances, bioproducts are being marketed at a premium to customers who are willing to pay for the associated environmental benefits. An example of this is food and beverage manufacturers packaging made with bioplastics (UNU 2005). For many firms, using more expensive bioproducts in place of traditional petroleum inputs may reduce costs of complying with environmental regulations, or improve corporate image and increase goodwill.

Firms are not the only organizations weighing the benefits and costs of new bioproducts. Due to issues of environmental and other long-term benefits versus immediate economic feasibility, governments around the world are deciding whether and how to support domestic bioproducts. Policy makers are taking a substantial interest in bioproduct development and commercialization for a number of reasons. Beyond the topic of climate change, bioproducts show promise in other key policy areas such as energy security, environmental sustainability, agriculture and rural development, efficiency, and innovation and the bioeconomy (OECD 2004). It is worth noting that these areas differ in importance depending on the nation involved; for instance, a reduction in dependence on foreign energy sources is of primary importance to the United States, while it might be

a secondary issue to potential opportunities for agriculture in Canada. Some of the major government considerations are energy security; economic diversification; employment opportunities; export market development; rural economic development; waste management; development of value-added products; and human health concerns (Industry Canada 2005).

2.2.3 Applications of bioproducts

Like biotechnologies in general, bioproducts encompass a wide spectrum of applications, with new uses being developed on a regular basis. Arguably the most prominent of these are fuel and energy. Production of ethanol transportation fuel, especially from corn or sugarcane, has grown exponentially in recent years. However, the focus of many research and development programs is shifting toward developing processes to transform crop and other residues into useable fuel and power. The obvious benefit conferred is that the input is a waste product from primary production; the bioproduct use does not have to compete with the primary use, e.g. food production for human or animal consumption. This in turn implies that the raw input cost will be relatively low. Note that this does not mean that biofuels will be cheap to produce. Despite the low cost of the input, costs for its transportation and processing are relatively high due to the large amount of input needed to convert biomass to energy using current technologies. While biofuels/bioenergy may hold the greatest potential in the long run, they are time consuming and costly to develop.

Other applications which show more short-run potential (as indeed many are already on the market) are products such as biochemicals and catalysts, bioplastics, and biofibers/panels, etc. These products vary substantially in their primary benefits, end users, development process, time and cost to market, and biomass inputs. Biochemicals, for example, are available for both consumer and industrial uses; depending on the individual product they may be safer to use, more environmentally friendly, and more efficacious.

These product categories are but a few examples of bioproduct applications. Table 2.1 illustrates some more specific examples of bioproduct substitutes for petroleum-based products, including their biomass sources. Note that some of the technologies required, e.g. transforming cellulose into automotive fuel, are not yet widely produced at a commercially-viable scale and are still being developed and/or refined.

Table 2.1: Bioproduct examples

Product	**Biological Raw Material**	**Replaced Petroleum-based Raw Material**
Electrical power	Wood, plant fibres	Coal, oil, natural gas
Diesel fuel	Vegetable oils, animal fats	Diesel fuel from oil
Automotive fuel	Ethanol from starch or cellulose	Gasoline from oil
Gas heating	Methane from animal or municipal waste	Natural gas (mostly methane)
Steel	Charcoal or oil from wood to reduce iron ore	Coke made form coal to reduce iron ore
Plastics	Polylactic acid from starch	Polyethylene

Floor covering	Cork, jute, flax	Polyvinyl chloride
Textiles, fabric	Hemp, flax, other plant fibres	Polyesters
Insulation	Straw, protein, glue	Polystyrene
Hydraulics, lubricating oil	Plant oils	Mineral oils
Wood glazes	Plant resins, oils	Polyacrylates, glycols
Fibre-reinforced materials	Hemp fibre, shellac resin	Carbon fibre, polyamide

Source: Adapted from Canadian Bioproducts Innovation Network, 2004.

2.3 Bioproduct Opportunities

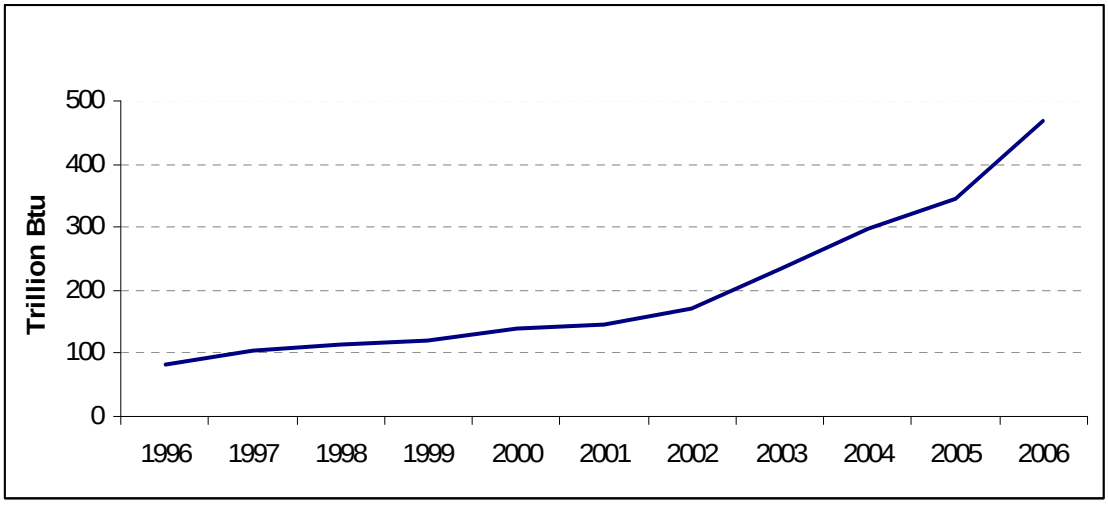
2.3.1 Global bioproduct opportunities

A host of bioproduct applications and opportunities exist in the global context, but there are obviously distinct opportunities for national specialization in particular types of bioproducts due to demand, technology competencies and resource availability. The emergence and success of a bioproduct industry in a given nation is contingent on the motivation for developing the bioproducts, and sufficient resources to produce for the end market. In many cases, industrial capacity and experience with innovation play a major role (UNU 2006); success stories tend to involve bioproduct development as an extension of an established domestic industry. However, for most products the market today is truly global, with consumer and industrial products being shipped anywhere with relative ease and sold in markets abroad.

In the United States, the major policy issue involves encouraging the production and consumption of biofuels in an attempt to reduce dependence on foreign energy sources.

Environmental motivations such as reducing greenhouse gases have also been cited as reasons for increasing the use of cleaner industrial biotechnologies. The largest anticipated impact is thus the transportation industry, and the policy instruments put in place for the production and use of renewable fuels appear to be working—consumption of fuel ethanol in the United States rose 55 percent (from 299 to 462 trillion Btu) between 2004 and 2006, as illustrated in Figure 2.1 (DOE 2008). Further, the ten-month consumption total for 2007 was 467 TBtu, up 25 percent from the ten-month total of 373 in 2006. Of the total consumed, the vast majority is produced domestically—89 percent in 2006—compared with crude oil, most of which is imported. The US has the ability, more so than nations such as Japan or those in the EU, to produce the feedstocks necessary as inputs to the biorefinery process. However, it may cost consumers in the food market so long as the both markets are competing for the same inputs. For this reason, many firms and research networks are working on developing viable conversion technologies which would use cellulosic materials such as crop wastes for inputs. The Department of Energy aims to develop cost-competitive cellulosic ethanol by 2012, citing the decrease in production cost of 55 percent between 2000 and 2005 (NREL 2007). The longer term goal of displacing 15 percent of gasoline use by use of renewable fuels is set for 2017.

Figure 2.1 Biomass consumption by United States transportation sector, 1996-2006



Source: http://www.eia.doe.gov/emeu/aer/pdf/pages/sec10.pdf

The EU seems to view industrial biotechnology as a tool to simultaneously improve productivity while decreasing emissions and environmental impacts, potentially boosting the competitiveness of their firms in world markets. Member nations typically do not have as substantial an agricultural base as the US, and what feedstocks are produced sell at a high price, bolstered by domestic agricultural support. However this is not an insurmountable barrier to participation in the bioproducts arena. Founded on a strong base of pharmaceutical biotechnology and nanotechnology firms, the knowledge and capacity for developing technology is certainly present. While biofuel production may not be a primary policy target—nor feasible from a production standpoint—there are other opportunities in the biomaterials sector. For instance, the EU is the world's foremost producer of enzymes for industrial purposes, turning out 75 percent of annual global production of 1.8 billion Euro enzyme market in 2004/2005 (Bio4EU 2007). The EU also produces a modest proportion of world bio-polymers; their 7 percent share in

2005 was valued at 55.3 million Euros and represented roughly 148 000 tonnes of output (Bio4EU 2007).

Brazil, often cited as the bioethanol success story, has been developing ethanol from sugarcane for the past 30 years. This movement, spurred initially by high oil prices and depressed sugar prices, received much support from both government and industry in order to reach its current stage. Much of the benefit has come from productivity improvements in the distillery process over the period—fermentation time has fallen 75 percent, yield increased 30 percent, and steam consumption declined 37 percent (UNU 2006). In 2002, sugarcane-derived bioethanol comprised 13 percent of Brazilian transport fuel compared with a global average of 0.4 percent; the nation exported 2.3 billion litres of its total production of 15.3 billion litres, representing 15 percent of domestic production (UNU 2006). Overall, the industry has resulted in the creation of an estimated 920,000 jobs in rural areas, making Brazilian bioethanol a rural economy success story as well.

2.3.2 Opportunities for bioproducts in Canada

Canada has its own set of bioproduct opportunities and challenges. Because bioproducts include a range of diverse products such as fuels, chemicals, catalysts, plastics, and fibres, the commercialization of these goods will necessarily impact the many sectors in which these intermediate products are used. Two examples of prime importance to

Canada are the automotive and manufacturing industries. The most commonly used form of biomass for firms is agricultural crop residue (Statistics Canada Bioproducts Development Survey 2003), meaning that bioproducts present significant market opportunities for agricultural feedstocks. The availability of inputs from domestic agricultural and forestry sectors provides Canada with an advantage when it comes to production of bioproducts using these inputs.

New technologies often face challenges with respect to market acceptance. A positive consumer attitude will certainly aid in the adoption of bioproducts. In the current biotechnology environment, some consumers may be wary of the implications of new technologies. However, a recent study shows that Canadians are familiar with and receptive towards bioproducts. The vast majority of Canadians approve of bioproduct development in general; they recognize many benefits from commercialization, and perceive the risks to be moderate to low (Industry Canada 2006). It appears to be much less controversial than other recent biotechnology developments such as genetically modified organisms (GMOs).

From the supply side, developers of bioproducts are seeing benefits to commercializing various products based on industrial biotechnology platforms. The most important benefits for Canadian firms overall are reduced environmental damages and/or greener products (Statistics Canada 2006). Other important benefits are reduced production cost and new market and product opportunities. These results imply that firms are seeing a

range of results from their bioproduct activities, and the benefits derived are both social/environmental and economic in nature.

2.4 The Bioproduct Development Process

Given the slim odds of transforming a given idea into a marketable product, a successful outcome may appear to be mostly serendipity. The development process can be very complex and consume vast amounts of time and resources. In this way, bioproduct development is somewhat comparable to the pharmaceutical development process. Like pharmaceutical biotechnology, the science behind an industrial biotechnology comes out of basic research and is ushered into applied research when an application is identified, at which point patents may be obtained. From there, further development takes place, which hopefully leads to a prototype which can be tested and possibly patented. If a successful prototype is established, a firm can proceed to commercialization and production stages. Throughout this process, funding is required; this funding may come from within the firm as well as from a variety of external sources such as equity/shareholders, venture capitalists, angels, grants, or loans.

While this general framework may be true of many high technology development processes, there are some instances where bioproduct development diverges from the pharmaceutical model. Two major examples of this are outlined as follows. First, the time to market is typically much shorter for bioproducts than for pharmaceuticals. This reflects in part differences in the underlying regulatory structure; products intended for

use in a human health setting must undergo extensive clinical and non-clinical trials in order to be approved for final sale. Another implication of the differences in regulation is that bioproducts may require less funding to get to market. Additionally, it may be possible for a single firm to take a technology from applied research all the way to market, a phenomenon rarely seen in the pharmaceutical sector. In this respect, it may have more in common with new product development as it takes places in industrial and manufacturing sectors. Secondly, there are important implications for bioproduct development regarding positive environmental spillover effects. Bioproducts can have significant external benefits in terms of both the environment and energy security. This second component sets bioproduct commercialization apart from both the general biotechnology and industrial product development processes.

The development process for bioproducts is conceptualized in Figure 2.2. While there are different ways of conceptualizing the development process, the method used below is similar to the notion of the idea-innovation chain (Hage 2005). This chain divides the entire process into several main tasks (e.g. basic research, product development, manufacturing, and marketing) which can each be subdivided further into activities. While the model appears linear, it does not preclude backward steps, or the notion that new research directions may be inspired by old ones.

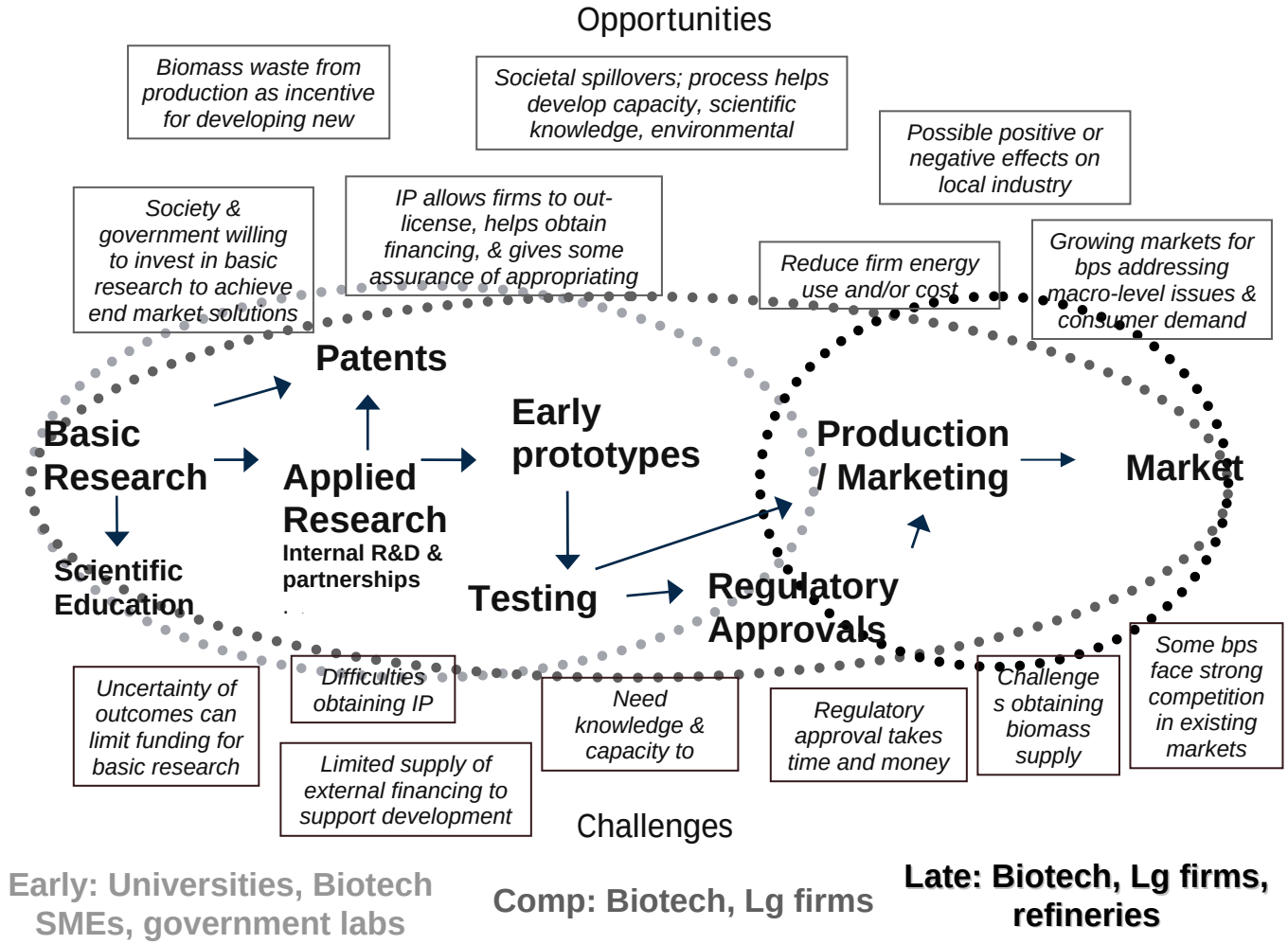
Major industry and academic players are classified as to their involvement in early development, late development, or comprehensive activity in all stages of development. Early stage agents are those involved in strictly basic research through product

development, while late stage agents produce, market and sell bioproducts but are not involved in early research. Comprehensive agents are those with broader involvement throughout the process, spanning basic research, product development, and commercialization. While many combinations are possible, there tend to be a few primary ways of organizing the development chain. The type of involvement (early, late, comprehensive) will inherently depend on the organization's goals and resources. A firm with a comprehensive focus requires a greater set of skills and competencies than one which focuses more narrowly on a given stage. Due to the nature of technology development and institutional support via intellectual property rights, it is possible for firms to either develop a technology and license or sell it down-stream, or conversely to obtain a technology or product which is nearly ready for market and complete the production and marketing stages.

The lightest circle in Figure 2.2 corresponds to the early focus described above. Those agents which may be involved in this stage generally include academia and government labs (responsible for a large part of basic research), and biotechnology firms of various sizes. Basic research, a precursor to applied research, is more exploratory in nature and may not have a particular target (e.g. product application) in mind. While such research may lack short-term commercial applications, it helps generate new knowledge by feeding it back into the scientific community (Audretsch et al 2002). Ideas with commercial potential are often spun out into small and medium enterprises (SME's). Many firms maintain their focus on this stage of the process because, although the research often requires highly skilled personnel, fewer resources and less capacity is

required than for developing or marketing a final product. Universities and government labs have been popular development partners due to their knowledge and research capabilities; they are becoming more so given improvements in the facility of technology transfer. Late stage development is most commonly undertaken by larger firms (biotechnology, manufacturers, refiners, etc) who have the capabilities and capacity required for turning out and selling a finished product. Industrial bioproducts may have associated economies of scale, making it even more necessary for extensive production resources. Comprehensive firms undertake activities along all stages of the development process, from basic research through product development and trials, and finally to production and sales. This can be very demanding in terms of resources, though it depends to an extent on the type of product. Developing a product from early stage to market requires not only technological know-how but also a host of complementary resources and skills, some of which may be specialized and some of which may be generic (Teece 1986). Thus, biotechnology firms with a strong background in all of the necessary development steps and extensive resources are likely to be involved in all development stages. In bioproducts, large manufacturing or forestry firms with a by-product from primary production sometimes become involved in the full development spectrum. While such firms may have less biotechnology research experience, they have a portfolio of other generic assets and skills such as product development, marketing, and production which can be modified for bioproduct use.

Figure 2.2 Conceptualization of the Bioproduct Development Process and Associated Opportunities and Challenges



Source: Adapted from Sparling and Vitale 2003.

A number of opportunities and challenges are present throughout the process, acting as both motivating factors and hurdles for firms looking to develop bioproducts. The initial incentive to develop a product can come from a number of sources—firms' anticipation of market demand for a novel product, government's willingness to invest in early-stage research in order to obtain macro-level benefits, and a firm's desire to reduce costs by finding an outlet for waste products are all possible industry drivers. Basic research has the added benefit of creating spillover effects, enhancing knowledge and capacity at the firm and national level. Although it is sometimes difficult to acquire funding for early stage research, IP protection is a mitigating factor, giving firms and investors some assurance as to the appropriation of returns from the technology and, in an economic sense, increasing the optimal level of R&D expenditure (Audretsch et al. 2002). While some basic and applied research gives rise to patenting opportunities, IP is not without its drawbacks; it can be time consuming and expensive to obtain, is not suited for all types of technologies, and does not generally provide plenipotentiary rights. Another challenge is the finite supply of internal and external financial resources which can be devoted to development, making exploratory research more difficult to justify.

Further along the development chain, product development, testing and regulatory approvals take place. These stages can prove challenging, although the extent varies widely—if the product is unlikely to require regulatory approval or substantial testing, it may reach the market in a short period of time. However, this is often not the case for novel biological compounds for industrial or consumer applications. Once a product is ready for market, there are the usual operational challenges such as refining processing

methods or obtaining reliable supply of biomass and other inputs; depending on the source, it can be extremely difficult to achieve consistent quantity and quality of biomass. Finally, many new bioproducts face stiff competition once on the market. Biofuels, cleaners, and plastics are all competing in existing markets, and while they offer some attributes beyond incumbent products, cost-competitiveness is still an important issue in determining market shares. Despite these hurdles, successful commercializing of bioproducts can generate benefits for the firm, the region, and the nation. Firms using their own by-products as inputs may be able to reduce energy use or disposal cost, or in some cases generate additional revenues by selling their product or biomass. Producing bio-based products can create local externalities such as air pollution, but also benefit the local community by creating jobs and infrastructure. Last, a major motivation is the profit firms hope to achieve once their projects reach fruition. Given the opportunities presented, there would appear to be substantial benefits for a sagacious firm able to identify the right project and negotiate development hurdles.

2.5 Conclusion

It is evident that a number of nations are pursuing the development of domestic bioproducts, hoping that they will provide solutions to economic and sustainability issues. Canada has a substantial supply of biomass inputs, and a growing bioproduct industry developing and producing many products. The complexities of the development process (and the societal issues surrounding bioproducts) imply that firms in this developing industry face many opportunities but also challenges. Firms may employ

different strategies for participating in the industry. The next chapter provides insight into the current state of Canadian bioproducts from both a firm and industry perspective. Recent changes in the industry will be discussed using data from the 2003 and 2006 Bioproducts Development Surveys.

3 Canadian bioproduct firms and their activities

3.1 Introduction

This chapter provides an overview of the bioproducts sector in Canada, noting the current composition of the industry, firm activities, and changes taking place in recent years. Strategic factors which play a role in the product development process are also discussed. The descriptive statistics presented here provide a basis for understanding the sector and its evolution and additional context for the econometric analysis undertaken in later chapters.

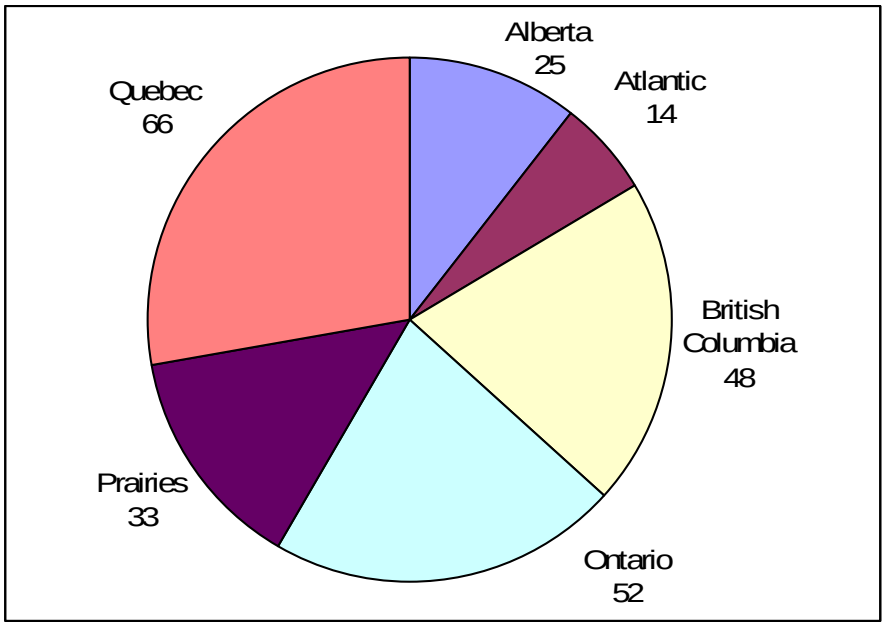
3.2 Firms and products

It is somewhat difficult to conceptualize the bioproducts "industry" in Canada, as firms involved in bioproducts generally have other lines of business also; indeed, many firms have expanded to include bioproduct activities as a way to access new markets (Sparling et al. 2006). Statistics Canada's Bioproduct Development Survey includes firms which participate in the development or production of non-food products from renewable biomass, regardless of their involvement or other activities. Characterizing the sector in this way helps to capture the full range of activities and development projects underway within the country.

According to the survey, there were 232 bioproduct firms in Canada in 2003. Firms were categorized as small (less than 50 employees), medium (50-149 employees) or large

(more than 149 employees). Two-thirds of firms were small, with the remaining third evenly split between medium and large sizes. They were distributed geographically such that Quebec had the largest proportion, at 31 percent. This is not overly surprising due to Quebec's existing dominance in the life sciences, and the infrastructure and knowledge networks in the region. Ontario and British Columbia rounded out the top three provinces by proportion of firms with 23 percent and 17 percent respectively. In 2006, the total number of firms rose slightly to 239; the geographic distribution is shown in Figure 3.1. As before, Quebec had the highest proportion of firms, with Ontario and British Columbia second and third respectively.

Figure 3.1: Number of Canadian bioproduct firms by region, 2006



Source: Statistics Canada's Bioproducts Development Survey, 2006

In 2003, bioproduct firms were involved in the development and production of 1,048 products in total (4.5 per firm). They employed 105 individuals on average, with 34 in bioproduct related roles. Averages revenues were $51.6 million with 26 percent derived

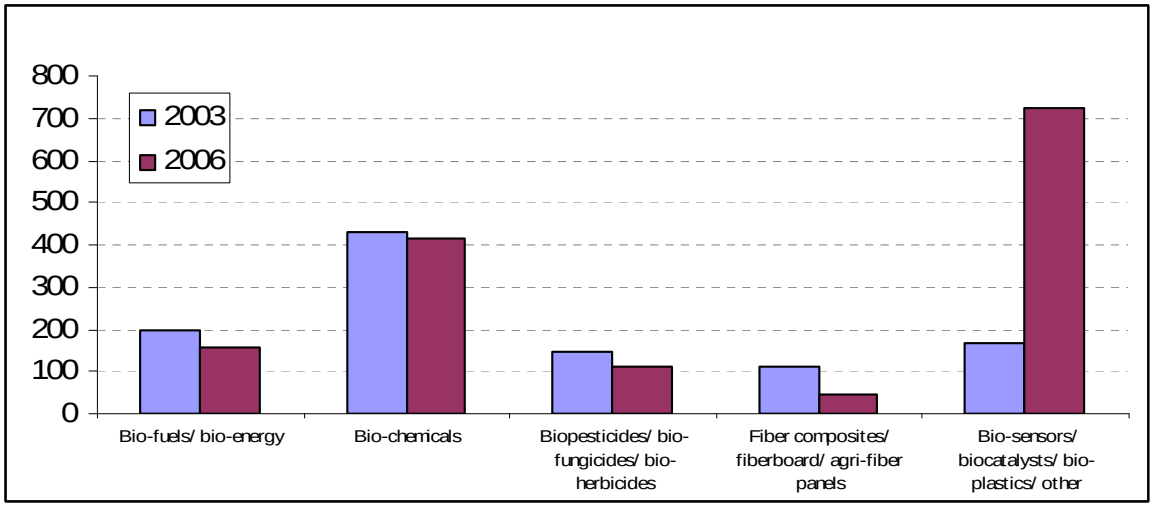
from bioproduct activities. Overall, $3 billion in revenues were generated as a result of bioproducts in 2003. Exports comprised nearly half of all bioproduct revenues.

Some noteworthy changes have taken place between the two surveys. The number of firms involved in bioproduct development rose slightly to 239 in 2006. Responses to a new question asking firms about their primary focus indicated a clear size effect: for small, medium and large firms, 62.7 percent, 46.0 percent, and 44.5 percent respectively indicated that their bioproduct activities were their main focus. Overall, there was a shift from large to small firms, with the combined medium and large firm population falling from 76 in 2003 to 40 in 2006 and the small firm population rising from 157 to 199 over the same period. As a result, the typical firm employed just 77 individuals in 2006, of which 17 were responsible for bioproduct activities. Total bioproduct revenues for Canada were lower at roughly $1.76 billion in 2006. This can likely be attributed to the fact that the typical bioproduct firm is now smaller than it was in 2003; bioproduct revenue per bioproduct employee actually rose from roughly $398,633 to $442,443 in 2006, an increase of 11 percent. Also, the total number of products in development and production was 1457 (6.1 per firm) in 2006—an increase of 39 percent over 2003 numbers.

Canadian firms were developing and producing a variety of different bioproducts in 2003. Those distinctly identified in the survey were biofuels, bioenergy, bioplastics, biochemicals, biosensors/catalysts, and fibre products. These product types were grouped into slightly broader categories for analysis, and the results showed that biochemicals

were the most prevalent type, accounting for 41 percent of all bioproducts. The number of products in each category fell slightly between 2003 and 2006, with one exception. As Figure 3.2 shows, the most common category in 2006 was the "bio-sensors, bio-catalysts, and other bioproducts" grouping. The dramatic increase in this category was due to a substantial increase in the number of "other" bioproducts, which rose from 168 to 726 and accounted for nearly all of the increase in total product numbers. Unfortunately, the survey does not provide a means of identifying what type of bioproducts this group could encompass, so it is difficult to draw any additional conclusions based on this observation.

Figure 3.2 Number of bioproducts under development/on the market by type, Canada 2003 and 2006



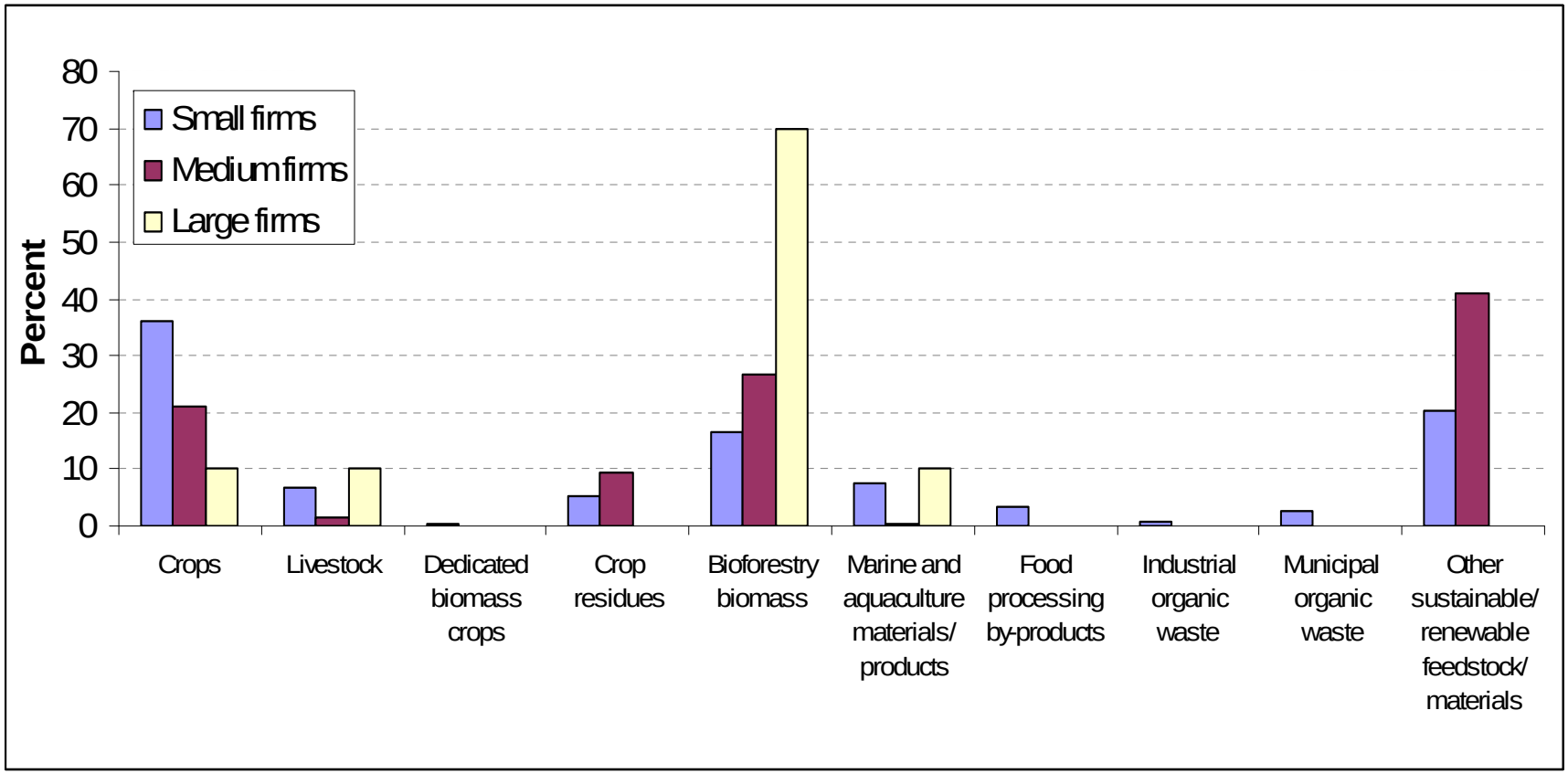
Source: Statistics Canada Bioproducts Development Survey 2003 and 2006.

3.3 Biomass use

Firms reported on average that 44.8 percent of their biomass came from agricultural sources, more than double bioforestry, which comprised 21.8 percent. Of the agricultural biomass, the majority came from crops, but livestock and crop residues were used to a

lesser extent. Use of dedicated biomass crops appears to be virtually zero based on numbers from the survey. There also appears to be a size effect at work with respect to inputs: this is clearly evident when looking at use of bioforestry biomass, and to a lesser extent, crop biomass (Figure 3.3). Large firms reported on average that bioforestry provided 69.8 percent of their biomass inputs while agriculture provided 20.0 percent. For small firms though, agricultural biomass was reported as comprising 48.5 percent of inputs, and forestry just 16.5 percent.

Figure 3.3 Percentage of biomass input by firm size, Canada 2006



Source: Statistics Canada's Bioproduct Development Survey, 2006

There is some variation in biomass origin as well: 10.8 percent of firms used their own on-site biomass, and 28.0 percent obtained it offsite but from less than 50 km away. At the other extreme, 24.4 percent of firms brought in biomass from over 500 km away. While most biomass is obtained from Canadian sources, firms reported sourcing 8.5 percent form the United States and 5.3 percent from other sources (for comparison 15.9 percent of all biomass was imported in 2003). This can be very costly due to the low value-to-weight ratio of most biomass, and is likely one reason for the increase in perceptions of transportation cost as a barrier to bioproduct development. The fact that 33.8 percent of firms said that they have the ability to substitute other forms of biomass might prove important in the event of a supply disruption or increasing cost in one specific area.

3.4 Other issues

3.4.1 Employment and revenues

Firms employed 3,974 individuals in bioproduct roles in 2006, down substantially from 7,851 in 2003 due to the overall shift towards smaller firms. This may have arisen partly from difficulties in filling available bioproduct positions; firms named insufficient capital/resources and lack of bioproduct-specific education as the greatest obstacles to filling positions in 2006. As with the number of employees, firm bioproduct revenues have declined from $3.1 billion to $1.8 billion, though R&D spending on bioproducts has decreased to a lesser extent, from $96 million to $81 million. Despite the apparent contraction in employment and revenues, bioproduct revenue per bioproduct employee

has actually risen from $399,000 to $442,000, possibly because the smaller firms dominating the industry (at least in terms of their numbers) manage to maintain their operations through contracting and collaborations.

3.4.2 Ownership

The vast majority of firms reported private ownership, but, not surprisingly, this was related to firm size. In 2003 19.8 percent of small firms, 36.9 percent of medium firms and 62.5 percent of large firms were publicly owned. By contrast in 2006, 13.5 percent of small firms, 67.5 percent of medium firms, and 60.0 percent of large firms were publicly owned, showing a decline in the proportion of small public firms and an increase in medium public firms. Overall, the proportion of firms which were public fell from 28.3 percent to 21.9 percent between 2003 and 2006, likely owing to the increasing proportion of small privately-owned firms. For those firms which were publicly owned in 2006, the majority stock ownership was Canadian in 44.4 percent of cases, American for 34.0 percent. However, the proportion of firms which were subsidiaries of multi-national enterprises (MNE's) rose across the three year period. As with ownership, there was a clear relationship with firm size: 15.8 percent of small firms, 41.5 percent of medium firms, and 75.0 percent of large firms were subsidiaries of MNE's in 2006.

3.4.3 Contracts and collaborations

Contracting was a major activity for firms in both years, though the number of contracts fell from 288 in 2003 to 128 in 2006. The majority of these arrangements were with academic institutions and government laboratories, both in terms of the number and the value of contracts. Nearly all contracts by value were for R&D purposes, and the

highest-rated reasons for contracting out were to access outside scientific expertise/knowledge and to increase physical capacity. Interestingly, large firms reported no contracts at all in 2006, possibly because their greater internal resources allow them to perform these functions in-house. The number of firms involved in collaborations also declined across the period, though just from 84 to 80. The primary purposes for collaborating were to conduct R&D and to access biomass; with respect to the latter, nearly all arrangements were with primary agriculture producers and other firms. In conducting R&D, partners were other firms, academic institutions, government labs, and agriculture producers. Less common purposes for collaborating were to assist with production/manufacturing, IP access, capital, knowledge/skills, accessing markets/distribution channels, and regulatory affairs.

3.4.4 Intellectual property

As discussed previously, intellectual property—especially in the form of patents—can help combat uncertainty in the development process. The proportion of firms owning patents did not change substantially between the two years. In 2006, 27.5 percent of firms held one or more patents with the Canadian Intellectual Property Office, 30.0 percent with the U.S. Patent and Trademark Office, 18.1 percent with the European Patent Office, and 7.2 percent with other offices. It is interesting, though not surprising, that more firms held U.S. IP than Canadian IP. Trademarks appeared to be another means of protection employed by firms; in 2006, 116 firms had bioproduct-related trademarks (the question was a new addition to the survey for 2006).

3.4.5 Financing

Another key aspect of developing products is obtaining funding for activities relating to the development and commercialization of products. Often firms seek funding externally for these purposes. In 2003, the most common purposes for seeking funding were R&D, proof of concept/pilot project, and operating funds. While R&D was still the most common reason in 2006, production/manufacturing capability and marketing/commercialization[1] claimed the second and third spots. Although R&D remained the most common reason, the proportion of firms seeking financing for this purpose fell from 44.8 percent in 2003 to 37.3 percent in 2006[2]. Also, 29.2 percent of all firms sought financing for production/manufacturing, and 24.3 percent for marketing/commercialization. It is possible that this shift coincides with having more products on the market or close to market in 2006 than 2003, accounting for an increasing need for capital to commercialize and produce.

A total of $219 million was raised by firms in 2006, less than the $297 million raised in 2003. Though a variety of financing sources were identified, the largest contributions originated from private placements (30.3 percent), grants (19.4 percent), and Canadian venture capital (12.5 percent). In addition to obtaining financing from these sources, 47.8 percent of firms applied for the Scientific Research & Experimental Development (SR&ED) tax credit in 2006, approximately the same proportion as in 2003. Applications totaled over $33 million for the most recent year. Other government-sponsored programs

[1] "Marketing/commercialization" was not one of the choices for the 2003 survey.
[2] This question asked if firms pursued financing in 2005/2006 rather than just 2006.

were used during 2006[3]; federal programs were accessed by 84 of 239 firms, and provincial/territorial/municipal programs by 54 firms.

3.5 Strategic factors

Bioproducts clearly have the potential to revolutionize a number of different industries, but there are still many challenges and obstacles to face before that scenario could become a reality. From an economic standpoint, firms must be able to provide products demanded by consumers at a price which consumers are willing to pay. This implies that at least two main perspectives must be addressed: that of the consumer and that of the firm developing/producing bioproducts.

First, there will need to be pubic acceptance and demand for the products being commercialized if the bioproduct industry is to grow. Uncertainty regarding consumer demand is often cited as a potential barrier. Despite positive results from domestic consumer opinion surveys, it is very difficult to predict whether these attitudes will translate into sizeable demand for bioproducts—especially when there may be a cost differential when compared with existing petroleum based products. Some of the potential barriers to consumer demand are limited access to or lack of availability of final products; high cost of bioproducts relative to conventional products; low consumer confidence in performance; lack of consumer awareness of products available; difficulty for consumers to differentiate between biobased and conventional products; and lack of

[3] This question asked if firms used government-sponsored programs in 2005/2006 rather than just 2006.

consumer awareness of environmental and socio-economic advantages of bioproducts (Industry Canada 2005).

Firm supply is the second requirement if there is to be any bioproduct market. While many firms have products on the market, they have also identified several barriers to commercialization and production of new technologies. Specifically, firms were asked in the Bioproduct Development Survey to identify the importance of several barriers to the commercialization of bioproducts; Table 3.1 shows the most important barriers as rated by Canadian bioproduct firms. The numbers provided in the adjacent columns represent the mean of the Likert-scale ratings (from 1 to 5 with 1 being "Low importance" and 5 being "High importance"). The barrier perceived by firms to be the greatest impediment to development in 2003 was lack of financial capital, while in 2006 it was transportation cost. Barriers which showed up in both years were input transportation cost, input prices, regulatory approval, and availability of financial capital.

Table 3.1 Top 5 Barriers to bioproduct development, Canada 2003 and 2006

	2006		**2003**	
1	Higher transportation cost of biomass	3.392	Lack of financial capital	3.442
2	Higher price of biomass	3.208	Cost/timeliness of regulatory approval	3.177
3	Difficulty in entering commercial marketplace	3.114	Higher price of biomass	2.829
4	Cost/timeliness of regulatory approval	3.054	Higher transportation cost of biomass	2.72o
5	Lack of financial capital	3.045	Unreliable supply of biomass	2.719

Source: Statistics Canada Bioproducts Development Survey, 2003 and 2006.

Some of these barriers are particular to bioproducts, while others are common to other industries. For instance, costs of obtaining and transporting biomass are particular to the bioproduct industry and have been one major source of concern in evaluating the feasibility of biofuels. The low value-to-weight ratio of most bioproduct inputs (e.g. crop and forestry residues) makes it difficult and costly to transport inputs over any substantial distance although development teams may be able to address this in time (Wyman 2007). On the other hand, difficulties in obtaining financing and regulatory approval are common to most biotechnology firms due to the particular development process that applies to these types of products. Because the time to market can be long and the outcomes uncertain, most biotechnology firms (especially small to moderate sized ones) must at some point seek external capital to finance product testing and regulatory approvals. This is challenging for the very reason that many technologies will eventually fail due to lack of efficacy, inability to meet regulatory standards, expanding development costs, insufficient consumer demand, or some combination thereof.

Firms were also asked to rank the importance of a number of benefits arising from their involvement in bioproduct development. They also rated the importance of different strategies to their actions over the course of the year. The five highest-ranked benefits from development are shown in Table 3.2. "Reduced environmental damages/greener and cleaner products" moved into the top-ranked benefit in 2006, rising from third in 2003. "Increased sales/market share", the former number one, fell to fourth in 2006. "Reduced production cost" appeared as the second-highest ranked benefit in 2006, after not making the top five at all in 2003. These changes may reflect increasing firm

awareness of the importance of sustainable business practices (or at least the importance to their customers), and the opportunities for reducing cost by using less costly bioproducts in their other production processes.

Table 3.2 Top 5 benefits from bioproduct development in Canada, 2003 and 2006

	2006		**2003**	
1	Reduced damage to the environment/ greener and cleaner products	4.056	Increased sales/market share	3.935
2	Reduced production cost	4.021	Developed new market niche/new products/differentiated products	3.865
3	Developed new market niche/new products/differentiated products	3.935	Reduced damage to the environment/ greener and cleaner products	3.807
4	Increased sales/market share	3.815	Improved product value/performance	3.689
5	Improved product value/performance	3.804	Increased product range	3.541

Source: Statistics Canada's Bioproducts Development Survey, 2003 and 2006

3.6 Conclusion

It is evident that the sector has undergone a number of changes in recent years, and as it is a relatively new sector, it may continue to evolve for some time. Large firms are becoming scarcer, with the focus (at least in terms of population) on small firms able to leverage their competencies by accessing capacity and knowledge from other players such as firms, government, and agricultural producers. Intellectual property and financing continue to play important roles. There appears to be a shifting of focus on a number of strategic issues, with more emphasis on the environmental benefits and reduced cost associated with bioproducts, and also the specific challenges associated with obtaining necessary biomass for production. The following chapter builds on some of these insights

to develop a conceptual framework linking innovation to firm and external characteristics, strategies, and resources.

4 Conceptual Framework

4.1 Introduction

This chapter aims to provide a critical review of the relevant literature and develop a conceptual framework to guide the forthcoming analysis. It begins with a discussion of both strategic management and the project selection decision processes at the firm level. Next, a framework is developed for economic decision-making, taking a resource-based view of the firm. Finally, specific variables and factors which affect the decision to innovate are proposed in the context of the resource-based view of the firm. The chapter attempts to approximate a realistic view of project selection, within the limitations of the data available. The framework presented leads into Chapter 5, which develops an econometric model for analyzing the survey data.

4.2 Strategic management

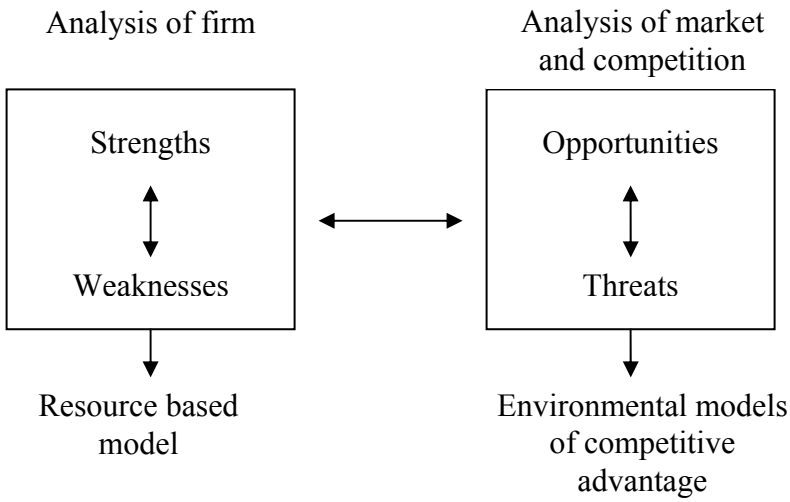
The major question in strategic management is how firms can achieve prolonged success. Naturally, this is a challenge in any industry; however, it can be an even more perplexing issue for high-technology firms, such as those developing bioproducts. Porter (1985) refers to technology as "a great equalizer, eroding the competitive advantage of even well-entrenched firms and propelling others to the forefront" (p.164). This may be attributed to a variety of causes, including the leader-follower nature of product development and uncertainty as to who will benefit from the development of a given technology (Teece 1986). Regardless of the industry, there have been multiple general methods suggested to address the issue of long-term firm success within an industry.

One approach takes the view that sustained competitive advantage may arise from a firm's ability to capitalize on significant resources in their possession. Firms should pursue opportunities which make use of their distinct assets and core competencies. The importance of the resources is derived from their value, rarity, imitability and scarcity (Barney 1991). The resource-based view has been used for econometric studies in a limited sense (e.g. Yeoh and Roth1999), but its primary usefulness has been in conceptualizing firm decision making and providing a means of understanding sustained comparative advantage (Oliver 1997, Barney 1991, Wernerfelt 1984).

An appealing aspect of the resource-based view is that it does not assume firms are homogeneous in their resources—that is, their ability to access critical resources such as knowledge, capital, and development capacity. Rather, one of the fundamental precepts is that differences in firm resources –and acknowledging these differences in management decision-making—is what leads to long-term business success.
Earlier work provides additional context for decision making by emphasizing the importance of environment and market characteristics. For instance, firm strategies and positioning should reflect the nature of the market, and the degree of competition (Porter 1980). Taking a somewhat broader view, the strengths-weaknesses-opportunities-threats model (Andrews 1980) suggests that both internal and external opportunities shape sustained comparative advantage. Figure 4.1 illustrates the linkages amongst the literature on competitive advantage.

Aspects of the literature emphasize internal analysis, external analysis, or both. When making decisions on which markets to enter or how to position themselves, firms generally want to consider both of these broad dimensions. Internally, they look to their own core competencies and abilities (strengths) as well as their shortfalls (weaknesses). Looking outward, firms must look for opportunities—markets which are not being well served, or have strong potential for growth. These must be weighed against possible threats, such as the presence of competition or other environmental hazards.

Figure 4.1 Linkages within strategic management literature



Source: Adapted from Barney 1991.

While it is crucial for firms to consider the opportunities and threats in a market, it is foolish to pursue a given project if it does not align with the firm's capabilities and competencies. In the high-technology sector especially, firms are better off not only pursuing projects which align with existing competencies but developing new capabilities

to capitalize on their valuable resources rather than looking at market conditions and competition (Teece et al. 1997).

4.3 The project selection decision

Firms in the bioproduct industry face the same problem as firms in other high-technology industries: the project selection decision. Deciding to pursue a given project is very important, as it represents (at least in part) the choice of the firm to engage in innovative activity. While the primary reason for undertaking a project is the anticipated profit to be earned, there is almost always an element of risk involved (Kinzig and Starrett 2003). Firms may invest millions of dollars in a project, only to find that it cannot be brought to market or that another firm develops a better project first. This element of risk, which varies depending on the individual project and technology as well as its development stage, is an important consideration for managers.

Even if there are profits arising from a project, they do not always come immediately or even in the short term at all. Often times, especially in the case of high technology firms, projects may lay groundwork for future products (e.g. basic research) or help to increase a firm's knowledge. Pursuing a given project may also further other company objectives. The factors affecting firm decisions are becoming increasingly complex as new concerns such as image or corporate social responsibility are coming to the forefront (Porter and Kramer 2006). In making development decisions, firms are forced to consider more factors than ever before. Such issues are being added to the existing milieu of concerns

over the development of the technology, and the value and accessibility of markets. A number of different approaches have been used to understand project decisions made by firms. Three major types are scoring models, economic models, and the portfolio approach, each discussed in more detail.

Scoring models

A common structure given to the selection decision is the group of scoring models. These models generally use a mathematical weighting of factors in additive form, with management "scoring" the project on a number of different variables; each variable has an assigned weight to reflect the value or importance of each variable or criterion to the firm (note that this does not allow for interactions between variables or scores). This type of model has been commonly used for choosing engineering projects, and has long pervaded literature in that area (Dean and Nishry 1965). Although intuitively appealing, it is naturally difficult to apply scoring models in cases with high levels of uncertainty, anddata is not easy to obtain. In many cases, the scoring process used on a day-to-day basis may be implicit.

Economic models

A separate group of tools provide a more economically intuitive means of addressing the issue. These include such measures as net present value, internal rate of return and payback. These have been widely used in the finance literature; one of the main advantages is the ability to recognize and account for cash flows across time, and compare projects with differing cash flows on a single measure (Martino 1995).

Drawbacks of these approaches include the assumption that cash flows are known with certainty (which is hardly ever the case) and the general exclusion or limited treatment of risk as a factor.

Portfolio approach

Due to this complexity and the inextricably linked nature of the firm's activities, it would be impractical and misleading to evaluate individual projects to the exclusion of all else. Rather, it is more appropriate to consider the firm's complete portfolio of projects, including those under development and products already on the market. This does not preclude the sequential evaluation of projects, but it does imply that the incremental value of a given project should reflect how the project is expected to change the value of the entire portfolio. Unless a firm has unlimited resources, it would seem unlikely that taking on a new project would not affect existing activities, whether the projects are in the same market or simply using the same set of resources. As such, there are generally interactions between projects within the portfolio, even if they appear at a glance to have little in common (Fox et al 1984). This effect is generally ignored by additive binary models (e.g. Dean and Nishry 1965).

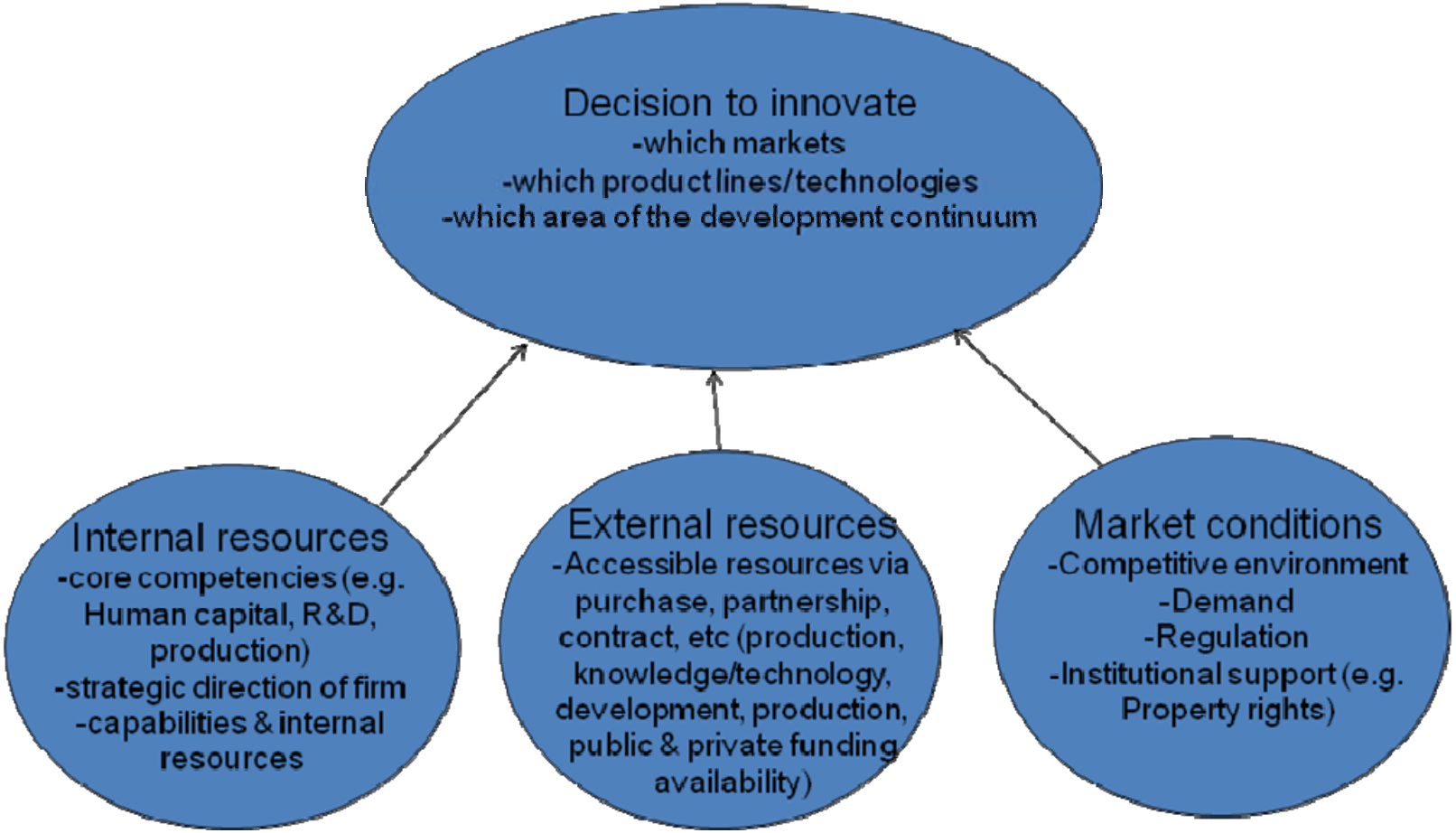
The project selection decision is given added complexity in light of the resource-based view of the firm, as various projects within a portfolio are often competing for the same resources. Another aspect of the project selection decision is the time horizon under consideration. The portfolio selection problem has been examined as both a static and

dynamic problem using a variety of economic and mathematic programming models (see Kavadias and Loch 2004 for an overview of important contributions).

4.4 Framework

The firm faces a conscious decision whether or not to pursue a given project. Resources must be allocated to the product's commercialization in order to bring it to market. In high technology industries, the allocation of resources can be substantial—significant amounts of time, knowledge and capital are devoted to develop a technology to the point where it becomes a marketable product. Because of this, it makes sense for firms to select projects which not only have market potential but which fit with their strategic direction and core competencies. The extent to which this alignment is necessary likely depends on the firm, the product under development, the stage of development and the resources required. Figure 4.2 gives examples of internal resources, external resources, and market factors which could play a role innovation decisions. A more thorough treatment of specific affecting innovation is presented in Table 4.1, following the framework section.

Figure 4.2 Conceptualization of resources affecting innovation decisions



The high-technology firm will generally have several projects in the pipeline, which may or may not be based on the same core technology platform. If a project is not entirely congruent with the firm's competencies, it might still be pursued. Other factors influencing the decision are the market potential, competitive threats or opportunities (e.g. market structure), and the regulatory environment. If a firm has a given technology but does not possess the requisite skills to fully develop it, commercialization is still possible so long as the resources are accessible externally. This notion is underpinned by Mathew's (2003) idea of a "resource economy", in which capital and knowledge assets flow within and between firms in networks. Such an idea is clearly consistent with observation in the biotechnology sector. It is fairly common for firms to take advantage of external resources through contracts and collaborations with universities, the public sector, and other industry players, and similarly it is unrealistic (and normally infeasible) for firms to possess all of those abilities internally. Alternatively, there may be an opportunity for a firm to make use of an existing by-product which is costly to dispose of as an input for a bioproduct. This is a potentially lucrative opportunity seen in few industries, which could help to not only increase firm revenues but also cut costs. A firm's choice of projects and positioning within the development continuum will depend on its own resources and capabilities, the availability and cost of other required resources, and market conditions such as anticipated demand, competitive pressures, the regulatory environment and the anticipated timing of resource needs and future revenue streams.

The firm's product development portfolio is comprised of all projects pursued by the firm in various stages of commercialization. While the firm may consider many projects, the

number under development and in production can be thought of as the total number of projects which the firm has reviewed and decided to undertake. At the firm level, the problem for decision makers is to maximize the firm's expected utility, a function of profits. Recognize that the profit for a given project is affected, in large measure, by the level of investment of hard and soft capital. The argument is that the allocation of money (i.e. hard capital) and firm resources (i.e. soft capital such as human capital and creative capacity) will affect: the firm's ability to innovate; the likelihood of success for any given projects; and the monetary benefits and costs associated with a successful project. Taken together, these dimensions work to determine the profit associated with each project.

In light of this, each project's profit is assumed to vary with the level of hard and soft capital invested in that project, stated as follows:

(4.1) $\pi_i = [REV_i - C(Q_i) - a_i - r_i]k_i$

Where REV_i is expected market revenue associated with the *i*th product/process, $C(Q_i)$ is the variable cost of production, a_i and r_i are the development and unit capital costs, and k_i is the hard and soft capital investment associated with the ith project. It is important to note that, *a priori*, the unit profit associated with investment of hard and soft capital is assumed to be random.

Revenue and cost components will be affected by the firm's internal resources, available external resources, and market conditions, discussed previously. This implies that profit will be greater, other things equal, when a project makes use of the firm's core

competencies and strengths, external resources which are relatively low cost/easily obtainable by the firm, in the presence of a favourable market environment. In particular, the firm's revenue will reflect the market environment as well as the firm's strategic positioning within that market and any competitive advantage. The cost variables will reflect the project's use of internal and external resources and the scarcity of such resources. While this may at a glance appear intuitive, it has important implications for the project selection decision. For instance, a smaller market may actually be more valuable to the firm if competitors have limited access to the resources required for continued production of the product. This type of sustainable competitive advantage becomes a consideration, especially for high-technology firms, when deciding which projects to undertake. Another important point is that some factors will not have an immediate effect on profits, so it is important to remember that the expected profit is best viewed as the discounted stream of future profits. A project might generate goodwill with the public which may not serve to increase profits for several time periods.

Equation (4.1), representing the profit equation for a given project, is naturally a subset of the firm's entire profits derived from the portfolio of projects. The firm will select over *n* possible projects to create its optimal portfolio, which may be comprised both of projects under development and products already on the market. The portfolio itself will change over time, as projects are added and sold or abandoned by the firm. The value of the firm's portfolio can be represented as the sum of the project's profits:

$$\pi = \sum_i \pi_i = \sum_i [REV_i - C(Q_i) - a_i - r_i]k_i \tag{4.2}$$

Where, to reiterate, $k_i \geq 0$ is the firm's investment of hard and soft capital in the project. It is also recognized that the firm's capital resources are constrained, and the sum of all hard and soft capital investment cannot exceed the total amount available for investment: $\sum_i k_i = \bar{k}$, the total amount of capital the firm has to allocate. Note that if $k_i = 0$, the respective project will not be pursued and thus not enter the portfolio; if $k_i > 0$, the project will enter the portfolio. This reflects the investment of both capital and knowledge/human resources, which represents the firm's overall internal capabilities. This notion of "soft capital" is not directly measurable, but could be captured using a latent variable.

The firm's optimization problem becomes:

$$(4.3) \quad \max_{k_i} \; EU(\pi) = EU\left[\sum_i (REV_i - C(Q_i) - a_i - r_i)k_i \right] \quad k_i \geq 0 \; \forall i$$

$$\text{subject to} \quad \sum_i k_i = \bar{k}$$

The associated Lagrange function is:

$$(4.4) \quad \max_{k_i, \mu_i, \lambda_i} \; EU(\pi) = EU\left[\sum_i (REV_i - C(Q_i) - a_i - r_i)k_i) - \sum_i k_i \mu_i + \lambda(\bar{k} - \sum_i k_i \right]$$

where μ_i, λ_i are the Lagrange multipliers associated with the non-negativity and capital availability constraints. Under mild assumptions (Herath et al. 2008), the expected utility of profit can be approximated using the mean-variance approach. Given the portfolio nature of the firm's problem, variance is actually captured with a covariance matrix, $\boldsymbol{\Omega}$. In this instance, the Lagrange is expressed as:

$$(4.5)\qquad \max_{k_i,\mu_i,\lambda_i} \; L = \sum_i (REV_i - C(Q_i) - a_i - r_i)\, k_i - \frac{\rho}{2} k'\boldsymbol{\Omega} k - \sum_i k_i \mu_i + \lambda(\bar{k} - \sum_i k_i)$$

where ρ is the Pratt-Arrow coefficient of risk aversion and *k* is the vector of capital allocations. The first order conditions are thus:

$$(4.6a)\quad \frac{\partial L}{\partial k_i} = REV_i - C(Q_i) - a_i - r_i - \rho \boldsymbol{\Omega}_i k - \mu_i - \lambda = 0 \;\forall i$$

$$(4.6b)\quad \frac{\partial L}{\partial \lambda} = \bar{k} - \sum_i k_i = 0$$

$$(4.6c)\quad \mu_i \geq 0, \quad k_i \geq 0, \quad \mu_i k_i = 0 \quad \forall\, i$$

Where $\boldsymbol{\Omega}_i$ is the ith row of the covariance matrix. Assuming an interior solution, the firm will choose its capital investment in projects such that the risk adjusted incremental benefits for each project are equated. In this manner, the relative investment share held by each project reflects its value to the firm, adjusted for risk, relative to the other projects undertaken by the firm. This decision rule is similar to Kavadias and Loch (2004), who recommend allocating the research budget dollar by dollar to the projects with the highest marginal values. Further, the proportion of the firm's total capital available for allocate across projects can be thought of as the share of that project in the firm's overall portfolio.

Note that it is possible for the allocation of capital to a project to be zero (i.e. the project is rejected) even if it possessed the highest expected benefit. This must be allowed due to the relatively common scenario, especially for small firms, in which there is insufficient cash flow to pursue the first-best project and so inferior projects will be pursued in the

interim. Firms may have to choose innovations which balance their portfolio rather than risky ideas which potentially have high long-term payoffs (Yeoh and Roth 1999).

The allocation of the capital measure used above is unobservable though it is of course known to the firm. Unobservatilitly of k_i arises because of the soft capital component. Projects with high capital shares (or portfolio weights) may have a higher expected payoff for the same level of investment as projects with lower capital investment (or portfolio shares), or they may simply be larger projects requiring significantly larger investments than other projects in the portfolio. Unlike financial market investments, project investments are not infinitely divisible. Projects generally have minimum threshold levels of investment. At the margin, however, the risk-adjusted anticipated benefits will be the same on all projects comprising the portfolio.

Observable variables include firm and some project characteristics, along with external market forces and policy conditions. These variables represent the internal, external and market characteristics assumed to drive the project selection decision. In this case, solving the first order conditions, in general terms, results in the following relationship:

(4.7) $$w_i^* = f(Int, Ext, Mkt)$$

where w_i* is the ith project share of the available capital, Int denotes internal factors, Ext denotes external factors, and Mkt denotes market conditions. The latent variable weights (or shares, w_i*) placed on a project will depend on internal scarce and valuable resources (which, according to the resource-based theory of the firm, is the root of competitive advantage), external resources and the market environment. These resources enter into

the firm's project selection through various elements. Anticipated revenues, for instance, are affected by market conditions such as demand and the competitive environment, as well as intellectual property rights. A product's costs, including R&D, are determined largely by internal and external resources; the relative costs and availability of knowledge, infrastructure, funding, production capabilities, etc all factor into the overall cost of a given project. The firm's decision takes into account all of these factors and constraints in order to most efficiently allocate their scarce resources amongst potential projects.

If a particular project under consideration is not pursued, (4.6a, b and c) and (4.7) imply that the expected benefit to the firm of investing at all, in light of firm resources, external resources, and market conditions, was lower than the incremental benefit of either a) investing further in an existing project or b) accepting a different project.

Recall that $w_i^* \geq 0$. In this instance an indicator function can be developed such that

$\mathbf{I}_i$ ($w_i^*>0$) = 1 if $w_i^*>0$ and 0 otherwise.

To utilize this indicator function and anticipating the empirical framework, note that the sum of $\mathbf{I}_i$ across all possible projects yields the count of the number of projects entering the firm's portfolio:

$$\sum \mathrm{I}_i = \textit{product count} = g(Int, Ext, Mkt)$$

Thus, the firm's decision to commence a project can be linked back to the set of internal and external resources and market characteristics which directly affect firm profits (and competitiveness in the long run) via revenues and costs of developing a given product.

4.5 Resources & innovation

The project selection decision becomes even more important when we think of the firm's choice in pursuing a project as the decision to undertake innovation. There are a variety of factors thought to influence innovation; taking a resource-based view, these factors could easily be grouped into firm or internal resources (I), external resources (E), and market characteristics and conditions (M). Firm resources might include capital available internally, knowledge/scientific abilities, chosen focus (e.g. early or late development stage), patents, and firm experience or age. External resources might include the ability to access additional capital, collaborations with other firms, universities or government, and in-licensing opportunities for IP. Pertinent market characteristics include demand conditions, the regulatory environment, the competitive environment, and policies in place to promote the development or commercialization of products.

As the opportunities and markets for exchanging resources improve, it may be expected that the relative cost of such resources may become more important than whether or not the firm actually possesses the resources internally (Mathews 2003); as such, the resources and strategic considerations outlined in Table 4.1 are hypothesized to play some role in firm innovation. While there has been little research investigating factors and resources specifically impacting the bioproducts area, important variables and their effects have been well-documented in other industries. Variables such as intellectual property, firm size, R&D, collaborations, and financing are fairly well-documented in the

innovation literature; there is no reason to suggest that similar analysis for the bioproduct industry will yield opposite results. However, some additional variables such as strategic focus, relative importance of bioproducts, strategic fit, competitive environment and regional effects are expected to yield results which are industry-specific. Variables in the table are grouped by internal, external, and market categories, and the hypothesized relationship for each variable with innovative activity is included, as well as relevant literature on the topic.

A number of specific internal and strategic factors are expected to have a relationship with innovative activity. Intellectual property has been found to be positively related to innovation, with much of this research being done in the closely-related area of pharmaceutical biotechnology. It is possible that the effect may be lessened here by comparison, as some types of bioproducts are not conducive to patenting. Innovation is expected to increase with firm size also, an effect which has been documented in several industries. The same may be said for age or firm experience in that firms building knowledge of the industry and technical aspects over time may be more likely to innovate. Research and development expenditures have also been shown to increase innovation, and have themselves been used as a measure innovation in some cases. As with IP, this effect is especially documented in pharmaceutical biotechnology, and may be less important here where more of the development process focuses on revising prototypes and getting products on the market than on basic research.

Firms' decision to focus on either early or late stage product development, based on their competencies and resource position, may also have an impact on the breadth of the portfolio. The relative importance of bioproducts to the overall activities is expected to play a role in this industry; since many firms focus primarily on other activities, it seems reasonable to expect that those firms will have fewer products than firms which focus on bioproducts. Firm ownership might be expected to influence innovative activity, in that developing innovations may signal value to investors. Finally, strategic fit and perceptions of benefits and barriers are expected to reflect both management's strategy and the firm's resource position in the context of its activities and environment.

In addition to the internal characteristics, a number of external factors are hypothesized to affect innovation. First, the need to obtain capital is an issue for many high technology firms, and once again there is substantial literature in the pharmaceutical industry to attest to this. It is expected here that firms which are able to access the required capital will have greater freedom to pursue a broad portfolio of innovations. Similarly, government funding may assist in defraying costs of development or production, allowing firms to invest more in innovating. Finally, collaborations have been shown to aid innovative activity. It is expected that this result will be supported here—the bioproducts industry is similar to other technology sectors in that firms normally do not have the full range of requisite competencies internally, and may at some point call on partners for the purposes of R&D, input sourcing, production, or manufacturing. Even when firms do possess the technical capabilities, joint ventures help to reduce the cost to each firm.

Last, market conditions and competitive environment are expected to be important to the firms' innovation decisions. The subsector in which a firm operates or focuses will likely influence innovation in that each area may have its own permutation of the development process, creating additional opportunities and challenges. For instance, it may be more resource-intensive for a firm to focus in the biofuels area than in biochemicals—in particular, the same amount of resources may not stretch across as many distinct biofuels innovations because each requires a greater devotion of time, knowledge, capital, and overall capacity than a single biochemical innovation designed in a laboratory. The region in which the firm is located is also expected to play a larger role than in some other industries. As with other biotechnology and information technology, regional innovation networks are likely conducive to fostering innovation in providing concentrated areas of intellectual and physical capital. In the case of bioproducts, region is expected to play a further role in that local and provincial incentives for developing bioproducts may exist, and also access to biomass is crucial to firms and the ability to source it locally and reduce transportation costs would appear to give firms a significant competitive advantage.

Table 4.1 Internal, external and market characteristics important to innovation

Internal & strategic (I)	Link to innovation	Hypothesized relationship with innovative activity
IP	Intellectual property may foster innovation by reducing uncertainty as to who will profit from innovations; while owners of IP don't always profit from the technology, IP is generally effective in product innovations and areas such as chemicals (Teece 1986); firms with IP are more likely to innovate (Hanel 2008) Note: in-licensed IP (as opposed to owned IP) can be thought of as an external factor	+
Firm size	Large firms may be more innovative simply because they have more assets/resources at their disposal; they may also have lower development costs due to scale	+
Age	Experience in an industry tends to foster innovation (Traore 2004)	+
R&D	R&D is often thought to be an important determinant of innovation; however, R&D intensity has also been shown to be more highly correlated with patent counts than with product or process innovation (Hall 2002); firms in manufacturing often produce innovations without R&D, however those investing in R&D are more likely to produce innovations (Hanel 2008)	+/-
Strategic focus	Firms with early focus or no focus (van Moorsel 2007) may have more products in the pipeline	+/-, -
Relative importance of bioproducts	Firms putting a higher priority on bioproduct activities relative to other firm activities may be more innovative	+
Organizational structure	Innovations in the pipeline may signal value to shareholders/investors (Rzakhanov 2004)	+ public
Strategic fit & resource	Firms using internal by-products as inputs may have fewer bioproducts; firms with relatively broad	+/-

challenges	benefits (e.g. access new markets) and fewer or less important barriers (e.g. difficulty with financing, access to human capital) may have more bioproducts	
External (E)		
Accessing capital	Financial markets value products under development and on the market (Rzakhanov 2004); uncertainty surrounding innovation may lead firms with more products to be more successful obtaining funding	+
Government programs	National-level funding improves chances of firm success and growth by providing funding not available through capital markets and by making the industry more attractive to skilled employees (Audretsch 2001); the tax credit has less impact on innovation compared with the direct subsidy in Canadian manufacturing (Hanel 2008)	+
Collaborations	Collaborations are beneficial for innovative activity (Baum et al 2000) and sales (Mohnen and Therrien 2003); collaborations enhance innovation and allow firms to capitalize on each partner's competencies (Baumol 2001); networks of collaboration help biotechnology firms grow and innovation arises from collaborative activities (Powell et al 1996)	+
Market (M)		
Competitive environment & nature of market	The competitive environment varies depending on the individual subsector. Type of innovation may also vary by subsector: a given amount of resources may be able to produce several small innovations in one industry (e.g. biochemical) or a single large one (e.g. biofuels	+ chemicals - fuels +/- plastics, other
Regional effects	Differences in strategies for commercialization and innovation, regional innovation networks and infrastructure may impact firm-level innovation (Audretsch 2001); Quebec firms most likely to product Canada-first innovations (Hanel 2008)	+/-

4.6 Conclusion

There is a substantial body of literature dealing with strategic management issues such as decision making. This literature outlines several approaches; the portfolio approach is highlighted here as it captures the interdependent nature of firm activities and the competition over various projects for scarce resources. These resources—both belonging to the firm and externally available—along with market influences are thought to drive innovation at the firm level through the project selection decision in which the firm chooses project weights in an attempt to maximize expected utility. A number of resources and factors which have been shown previously to affect innovation, along with some others which are hypothesized to have a relationship, were presented. In Chapter 4, these characteristics form the basis for a set of explanatory variables in a model designed to help explain innovative activity.

5 Empirical Model and Data

5.1 Introduction

The previous chapter introduced a resource-based framework to motivate innovation and product development decision-making at the firm level. Variables which have been shown to influence innovation were discussed and hypotheses presented in Table 4.1. This chapter begins with background on the Bioproduct Development Survey, which is the data source for this research. Next, survey variables and innovation factors established in the literature are used to develop a model to help explain bioproduct innovation. This empirical analysis, comprised of a negative binomial regression model and supporting principal component analysis, is presented and discussed.

5.2 Statistics Canada's Bioproduct Development survey

The Bioproduct Development Survey (BDS) was commissioned by Agriculture and Agri-Food Canada and conducted by the Science, Innovation and Electronic Information Division (SIEID) of Statistics Canada. The goal of the BDS is to provide information on the emerging bioproduct industry which would be of use to provincial and federal government decision makers as well as industry associations. To date, two versions of the survey have been conducted. Data was first collected from firms across Canada reporting involvement in bioproducts for the years 2003 and, in a second survey, 2006.

Although existing biotechnology surveys (e.g. Statistics Canada's Biotechnology Use and Development Survey) have captured some information on firms involved in industrial biotechnology (Traore 2003), the BDS is the first survey to focus on bioproduct firms and their activities and characteristics. The target population of the survey included Canadian firms involved in bioproduct development and/or production, as specified by a set of North American Industry Classification System (NAICS) codes (see survey methodology for details). Bioproducts were classified into several categories: bio-fuels; bio-energy; bio-sensors; bio-catalysts; bio-chemicals; bio-plastics; bio-pesticides/bio-fungicides/bio-herbicides; fiber composites; fiberboard/agri-fiber panels; and other bioproducts or biomaterials.

The survey questionnaire was sent to approximately 600 firms identified from the 2003 Biotechnology Use and Development Survey and a list of firms obtained from federal partners, provincial/territorial bioproducts industry associations and industry experts. The total estimated firm population was 232 in 2003. This number was obtained by assigning weights based on homogeneous groups of respondents within the survey in order to compensate for non-response factor, and is a standard practice for Statistics Canada's surveys.

Respondents answered questions on a variety of topics encompassing firm characteristics, perceptions, and strategic considerations. The main focus of the survey was on bioproduct activities, although most firms were involved in other business lines as well. In this chapter, responses to questions dealing with firm and external resources,

management strategies, and markets will be used as regressors in a model to help explain firm-level bioproduct innovation. Selection of explanatory variables is guided by Table 4.1, and includes factors which have been shown to influence innovation in other industries along with those which are expected to play a role due to the unique nature of the bioproducts industry.

5.3 Measuring Innovation

Measuring innovation is not a new idea. It has been attempted in both business and economic realms, using various approaches and conceptualizations. The ability to quantify innovation and relate specific factors to it is very appealing on a number of fronts—from the firm's perspective, the ability to undertake and succeed in certain types of innovation may be necessary to stay competitive in their markets. At a macro level, there has been support for technological advancement as a determinant of economic growth from Schumpeter to Romer. However, there are many issues surrounding the measurement of innovation. These include the precise definition of innovation, which may vary depending on the goals of the research and even the nature of the specific industry; the necessity of using measurable proxies in place of desired variables; and, in a similar vein, whether or not it is beneficial to use constructs rather than single measures of innovation.

First, the idea or definition of innovation may vary depending on what the authors wish to study. Innovations can be conceptualized in a general sense as either product or process,

and radical or incremental. For a given study, only certain types of innovation (e.g. radical as opposed to incremental) may be of interest to the researchers. If the focus of the study is on new pharmaceuticals, for instance, the innovations of interest will primarily be radical product innovations. Similarly, there is the question of whether the innovation is "new" in the context of the firm or industry, the nation or the world. An updated version of the Oslo Manual definition of innovation states that:

> *"An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations." (p46)*

Further, as product innovation is the main focus in this study:

> *"A product innovation is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses." (p48)*

This definition serves to emphasize the importance of implementation and is consistent with the notion of output measures of innovative activity; it should be the end goal of innovation to provide something novel which is actually useful in nature. An important clarification for the purposes of this study is that product innovations need not be on the market, but those still in development stages are innovations as well.

Once scope of innovation or innovative activity is decided on, there is still often the issue of how best to measure it. In many instances the ideal are either a) intangible or b) immeasurable. For instance, an intangible input of the innovation process might be

scientific knowledge; a tangible correlate of this would be the number of scientific employees, and measurable proxies would be man hours or payroll (Freeman, 1982 p8). On the output side, an intangible variable might be new inventions, which could be measured using patents, patent applications, or new products on the market.

Authors have used different variables and constructs as measures of innovation through the years. Innovation can be measured through the use of case studies, trade publications, surveys, and input or output indicators (Unger 2005). Input measures might include R&D, number of researchers/man hours; outputs could be marketed products, patents, sales dollars or percentage of sales from new products. Often times, the critical factor is the available of data on either the measure or a suitable proxy.

While indicators such as R&D outlays, number of researchers, and time to market are generally correlated, this correlation varies strongly depending on the project and market (Hage 2005). The choice of an indicator will depend on the industry—for instance, R&D may be an appropriate measure for the biotechnology sector, as the road to commercialization as project outlays correspond highly with innovative output (Hagedoorn and Cloodt 2002). For high-tech industries, R&D expenditures, patent counts or citations, or new products correlate highly enough to be used either as a construct or individually to capture innovative performance (Hagedoorn and Cloodt 2002).

Innovation from an economic perspective tends to focus on indicators found in the production function – e.g. R&D, labour, capital stock, and product output (Unger 2005). While this view will fail to capture certain types of innovation such as organizational innovation, it is suitable for studying product innovation. While there has not been any published work studying innovation in the bioproduct sector, this method has been used for studying product development innovation in the biotechnology sector (van Moorsel et al. 2007, Rzakhanov 2004). Thus, using a measure such as number of products in various stages of development would likely lend itself well to studying the bioproduct industry.

Admittedly, the use of a product count does have shortcomings. As noted in van Moorsel (2005), measuring strictly the number of products does not take into account the possibility of projects which are more or less valuable, more or less intensive, or more or less novel. A firm with a single high-value bioenergy project will undoubtedly appear less innovative than one developing several medium-value biochemicals. However, one of the key aspects of measuring innovation is the link to commercialization. The number of products under development is, as mentioned previously, more closely tied to eventual commercialization of innovations than is R&D expenditure or patent counts.

As many different approaches have been taken to solving this problem, it would appear that the most appropriate solution can only be reached by considering the industry of interest, as well as the goals of the research. There is no "one size fits all" indicator which best captures innovation under all circumstances. That being said, product count is

well suited to measuring product innovation, as it is more closely linked to implementing a new product (i.e. via commercialization) than other measures such as R&D or patents.

5.4 Empirical Model

The proposed model estimates the impacts of internal, external, and market characteristics on a firm's innovativeness. As described in the preceding section, this innovativeness is modelled as a count of the total number of products a firm has under development or on the market, and is assumed to be affected by a set of regressors which are the resources/factors affecting the firm. Product count has been previously employed to measure innovation in high-technology industries such as biotechnology. The primary regressions will centre on the entire sample in 2003 and 2006, providing grounds for comparison and determination of if and how innovation and its drivers have changed between the two survey years.

As outlined in the previous chapter, the firm is assumed to choose weights representing the proportion of their portfolio a given project makes up. This choice is made based on the anticipated revenue and cost streams associated with the project, which in turn depend on a set of internal, external, and market characteristics. The primary challenge of this approach is that the project weights, which are between zero and one, are unobservable due to data limitations.

Thus we can say that the latent variable is:

$w_i^* \geq 0$

However, while the specific value of each weight is unknown, the selection of a given project (i.e. $w_i>0$) is observable:

I_i (w_i*>0) = 1 if w_i*>0 and 0 otherwise

I_i thus carries a value of zero or one for each project, and we can observe those projects for which I_i =1. It is evident that the sum of the I_i's represents the total number of projects within the firm's portfolio. The indicator will thus be an integer count of the number of products a firm is pursuing or has on the market, which is representative of the decision to undertake innovation.

$$\sum I_i = g(Int, Ext, Mrkt) = product\ count$$

In this manner, the latent variable concept incorporating portfolio weights can be mapped to an indicator function which will capture firm innovation decisions.

The dependent variable—total number of products under development/on the market—is a count variable, meaning that it is a non-negative integer value. Further, the count will be strictly positive in this particular case as the survey respondents were firms with at least one bioproduct among their activities. The average number of projects per firm in 2003 was approximately 4.5, but individual observations could vary anywhere from one to infinity; realistically, one would expect the number of projects to be much lower due to the finite availability of resources.

Count data is fairly common, and because of its properties, requires special attention. For the ordinary least squares estimator to be unbiased and inefficient, the errors must be distributed normally, and the dependent variable should be continuous. By contrast,

count data takes on integer (discrete) values and generally has a non-normal distribution. Specifically, the distribution of count values will be skewed to the right, and observations will tend to be concentrated at the lower end of the scale. Using an ordinary least squares regression on count data is thus inappropriate unless the mean count is unusually high. A model specifically designed to address these issues makes use of a skewed distribution such as Poisson or negative binomial, which is more appropriate.

5.4.1 Poisson Model

The Poisson model allows for estimation of the conditional mean function, E(Y|X) where the dependent variable is discrete in nature. The Poisson distribution of Y has the density function:

$$\Pr[Y = y] = \frac{e^{-\mu}\mu^{y}}{y!}, \text{ y=0, 1, 2...}$$

where μ_i is a parameter representing the intensity or rate of increase in Y,

$\mu_i = \exp(x_i\beta)$ or $\ln(\mu_i) = x_i\beta$, in log-linear form. Note that $E(Y_i)=V(Y_i)= \mu$,

that is, the conditional mean and conditional variance will by definition be equivalent, a property known as equidispersion.

In the Poisson regression, the intensity parameter is assumed to vary with the regressors $x_i^{'} = [x_{1i},...,x_{ki}]$ and set of parameters β such that $E[y_i \mid x_i] = \mu(x_i, \beta)$. In this way, y_i given x_i is Poisson-distributed with a density of:

$$f(y_i \mid x_i) = \frac{e^{-\mu_i}\mu_i^{y_i}}{y_i!}, \text{ yi=0,1,2,...}$$

However, the condition that the mean equals the variance may be too restrictive—if the variance is greater that the mean (overdispersion) or smaller (underdispersion), the Poisson distribution is clearly inappropriate. As overdispersion is an especially common phenomenon (Blundell et al 1995, Trivedi 1997), it is important to find a way of removing the mean-variance equality imposed by the Poisson model. One way of doing this involves using a negative binomial model rather than the Poisson model.

5.4.2 Negative binomial model

The negative binomial distribution allows for maximum likelihood estimation using more than one parameter so that the conditional variance may differ from the conditional mean. This model, along with others, addresses the issue of over-dispersion by allowing for additional parameter(s). The negative binomial model is distributed with a density:

$$f(y \mid \mu, \alpha) = \frac{\Gamma(y + \alpha^{-1})}{\Gamma(y+1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right)^{\alpha^{-1}}\left(\frac{\mu}{\alpha^{-1}+\mu}\right)^{y}, \quad \alpha \geq 0$$

which reduces to the mean if α = 0. The Poisson model is, in fact, simply a particular case of the negative binomial model (specifically α=0). The NB2 model, shown above, and the NB1 model are additional specifications of the negative binomial model suggested by Cameron and Trivedi (1998) where $E(Y_i) = \mu_i = \exp(X_i\beta)$, identical to the Poisson model, however $Var(Y_i) = \mu_i + \alpha\mu_i^p$. NB2 sets p=2, such that $Var(Y_i) = \mu_i + \alpha\mu_i^2$ and NB1 sets p=1.

There are a number of negative binomial specifications e.g. negbin1, negbin2 (Cameron and Trivedi 1986) that arise by setting constraints on parameters. For the purposes of this study, regressions will be run using both NB1 and NB2 specifications to determine if there is a significant difference. Note that other models besides the negative binomial model exist, and are also restricted cases of the general Poisson model.

5.4.3 NB2 MLE Estimator

In the case of the NB2 model, the maximum likelihood estimator β is consistent so long as the conditional mean is correctly specified (Cameron and Trivedi 1986). Additionally, because of the model specification the interpretation of the estimate is somewhat more complex than for ordinary least squares. In particular, since

$$E(Y) = \exp(X_i\beta)$$

$$\frac{\partial E(Y)}{\partial X_j} = \beta_j \exp(X_i\beta)$$

such that a one unit change in a continuous regressor X leads to a change in the expected value of Y by $\beta_j \exp(X_i\beta)$.

Due to the desirable properties of the NB2 model and its estimator β, this specification will be used in the forthcoming analysis. For 2003 and 2006, the total count of bioproducts under development and on the market will be regressed on explanatory variables from the BDS. These variables are proxies for the set of internal, external and market characteristics described previously. Undertaking regression analysis for both

years will allow for the comparison of resource and factor influences over the time period. Those changes occurring over the intermediate years may help to predict future changes and/or overall trends in the sector.

5.5 Principal component analysis

Survey responses to three questions on benefits, barriers, and firm strategies contain valuable information about the firm's resources and strategic focus. As mentioned in Chapter 3, survey questions simply asked firms to rate the importance of each of several items, which are given. The items are ranked using a five point scale, with 1 denoting "Low importance" and 5 denoting "High importance".

Ordinal comparisons can be made using responses for a given firm and also across firms to determine which benefits, barriers, and strategies were most important. However, it may also be the case that the same factor or attitude is driving responses on a number of different items within a question—for instance, firms who gave a high rating for "Increased product range" might also give a high rating for "Increased sales/market share". It thus becomes desirable to identify the underlying construct which might be causing the responses to particular items.

Principal component analysis attempts to maximize explained response variance within a question, and by doing so yields a number of orthogonal components which account for the variation in the responses. Thus, item responses are "loaded" onto the components or

factors based on the extent to which that component explains deviations in the item response. These factor loadings help determine which items are fundamentally important to that component, and from them multi-item scales can be constructed. Principal component analysis is ideal in this instance because it allows for an exploratory approach; factor analysis, by comparison, normally relies on a presupposed model or functional form relating the variable to the factors (Jolliffe, 2002, p151). While this could be accomplished using items across all three questions, here case each question is considered separately. This is done with the hope of determining specific attitudes towards each group (benefits, barriers, and strategies). Any components arising from this analysis will be used to compile multi-item scales, which will in turn become explanatory variables in the product count regression, representing the firm's strategic motivations.

5.6 Conclusion

There are a variety of ways to measure innovation. The method used here utilizes product counts as a measure of innovative activity. These product counts become the dependent variable in a count data model. The model developed uses a negative binomial specification to estimate the impact of various firm, external and market characteristics hypothesized to impact firm-level innovation. Separate regressions will be run for 2003 and 2006 data to allow for comparison of innovation factors. Explanatory variables will include constructs from principal component analysis in addition to proxies for other internal, external and market characteristics.

6 Results

6.1 Introduction

The previous two chapters developed conceptual and empirical frameworks culminating in an econometric count data model for analyzing determinants of innovative activity in bioproducts firms. A number of internal, external and market factors and characteristics thought to be important to innovation were introduced and discussed. This chapter begins with a description of the principal component analysis undertaken for benefit, barrier, and strategy questions, which provide information on strategic factors. Multi-item scales developed from the factors obtained have been used as explanatory variables in the regression analysis. Finally, results of the negative binomial model developed in Chapter 5 are presented along with a discussion of significant variables. While the focus is on the current state of the industry, some comparison of the 2006 and previous 2003 results is also undertaken.

6.2 PCA results

Benefits

Table 6.1 shows the mean values and standard deviations for items in the question "Benefits from the development/production of bioproducts". This question asks firms to rate the importance of a number of possible benefits the firm perceives from their bioproduct activities. The mean values represent the average rating for all firms, on a scale of 1-5, for each item, where 1 denotes low importance and 5 denotes high importance. Thus "Reduced damage to the environment/greener and cleaner products"

was the highest-rated benefit overall, with a mean score of 4.05. The second and third ranked benefits were "Reduced production cost" and "Increased product range" respectively. While and "other" item was included in this question (as well as the barriers and strategies questions), its mean importance was very low and it had virtually no correlation with the other items—as a result, it is dropped from the remaining analysis.

Table 6.1 Perceived benefits from development of bioproducts, 2006

	Mean	SD
Reduced damage to the environment/greener and cleaner products	4.05	1.192
Reduced production cost	4.00	1.399
Increased product range	3.95	1.136
Increased sales/market share	3.86	1.119
Promotion of community development	3.80	1.282
Reduced energy consumption	3.59	1.416
Improved product value/performance	3.53	1.273
Developed new market niche/new products/differentiated products	2.83	1.324

Note: Mean responses for each item are not significantly different from 3.

Some assessment of validity is important; this serves to indicate whether the items are highly correlated and thus strong candidates for reduction via principal component analysis. The Kaiser-Meyer-Ohlin statistic (Kaiser 1970) provides a measure of sampling adequacy which identifies common variance between variables relative to unique variance. A high KMO implies that variance in one variable can be largely measured by the variance in other variables. The KMO ranges from roughly 0.5 to 0.9, with levels over .70 considered acceptable—its value for the benefit items was 0.716. One possible

reason that the KMO is low is that there are only eight items—the KMO increases not only with the level of correlation but also with the number of variables and observations. Bartlett's test of sphericity tests the null that the items responses are not correlated (i.e. the correlation matrix is in fact the identity matrix). The test statistic is distributed as a chi-square with (p(p+1))/2 degrees of freedom where p is the number of variables. Put another way, the degrees of freedom equal the number of unique entries in the correlation matrix. The test statistic in this instance is 232.715, leading to a clear rejection of the null hypothesis of a diagonal correlation matrix at the one percent level. Based on these tests, there is sufficient evidence of underlying factors explaining responses to more than one item.

Cronbach's alpha ranges from zero to one based on the multi-item correlation, and provides a measure of reliability by examining how responses are correlated over different observations. For the benefits question, Cronbach's alpha (Cronbach 1951) is 0.751—while this is not particularly high, values of 0.70 or greater are considered sufficient. The table also shows how the internal consistency changes if each individual item is left out of the scale. Dropping any item with the exception of "Other" lowers Cronbach's alpha; however, if we remove "Other" from the scale, our reliability measure rises to 0.767. Due to the infrequent use of the item and its low correlation to other items, it has been dropped from the principal component analysis.

The PCA performed using SPSS yielded two components with eigenvalues over one. Higher eigenvalues are desirable in that the component explains a higher proportion of

the total variance in the combined group of item responses. These two factors are retained in accordance with Kaiser's criterion (Kaiser 1960). Together the two components explain 60.3 percent of the total variance in responses.

The component matrix in Table 6.2 shows the factor loadings for each component, representing the extent to which each item is captured by that component. Heavily-loaded items in each factor are in bold. The orthogonal varimax rotation of the initial solution provides more insight than the initial solution. It rotates the components in order to obtain more extreme factor loadings given the number of extracted components while preserving the relative positions of the items (Jolliffe 2002 p.153).

Heavily-loaded factors—those which are explained primarily by each component--for the first component included the four product- and sales-oriented items. Accordingly, this component has been named "Product/sales benefits". The remaining four items, dealing with energy consumption, production cost, environmental benefits, and community development, load heavily onto the second component. The second component has been called "Cost/environmental benefits". Cronbach's alpha for the multi-item scales based on retained components are 0.822 and 0.703 respectively.

As there are two separate regressions for 2003 and 2006, it is important to determine whether the same components can be used with the 2003 data—if there have been changes in attitudes or perceptions, it may be unreasonable to impose the same factors on the previous year's data. Further, there were minor changes to the items included in each

question. To address these issues, Cronbach's alpha was computed for all components from the 2006 analysis using 2003 data. For the benefits question, alpha was 0.751 for the first component and 0.840 for the second, which would indicate that the 2006 components are still a good fit for the 2003 data. This precludes running separate PCA for 2003 and allows for greater comparability between regression years as scales are constructed from the same components.

Table 6.2 Benefits PCA- Rotated component matrix

	Product/sales benefits	**Cost/environmental benefits**
Increased product range	**0.863**	0.052
Improved product value/performance	**0.803**	0.111
Developed new market niche/new products/differentiated products	**0.788**	0.087
Increased sales/market share	**0.730**	0.226
Reduced energy consumption	-0.005	**0.872**
Reduced production cost	-0.007	**0.680**
Reduced damage to the environment/greener and cleaner products	0.25	**0.670**
Promotion of community development	0.267	**0.633**
Percent variance explained	39.423	20.850
Cronbach's alpha	0.822	0.703

Barriers

The "Barriers" question asked firms to rate the importance of 11 barriers to bioproduct development on the same 5 point scale as the benefits question. More important items in

this question are the higher transportation cost of biomass (mean =3.47), higher price of biomass (mean=3.14), and difficulty entering the commercial marketplace (mean=3.13). Items were reasonably well correlated with the exception of "other", which was once again dropped from the remaining analysis. Cronbach's alpha for all items was 0.754, and rose to 0.780 with the removal of the "other" item.

Table 6.3 Perceived barriers to the development of bioproducts, 2006

	Mean	SD
Higher transportation cost of biomass	3.47	1.265
Higher price of biomass	3.14	1.212
Difficulty in entering the commercial marketplace	3.13	1.209
Cost and timeliness of regulatory approval	3.05	1.378
Lack of financial capital	3.01	1.456
Unreliable quality of biomass	2.83	1.472
Unreliable quantity of biomass	2.76	1.463
Lack of skilled human resources	2.55	1.247
Lack of adequate product standard certification	2.55	1.298
Restrictions on IP rights	2.37	1.178

Note: Mean responses for each item were not significantly different from 3.

The Kaiser-Meyer-Ohlin measure was 0.726, again sufficient, while Bartlett's test statistic was 330.867, which is significant at the one percent level. The principal component analysis yielded two usable components with eigenvalues greater than one. Together, these factors explained 55.6 percent of the total variance in responses.

Heavily-loaded items for each component in Table 6.4 are presented in bold. The first component includes a number of commercialization barriers which are by no means specific to the bioproduct development. Challenges involving regulation, human resources, commercialization, and intellectual property are rampant in the biotechnology industry and, to various extents, other high tech sectors as well. This factor was thus named "Technology commercialization barriers" to account for the fact that they are development barriers rather than strictly bioproduct barriers. The remaining four items, which load heavily onto the second component, all involve bioproduct-specific barriers. Besides the traditional technology development barriers, some firms clearly face costs and supply hurdles which arise due to the unique nature of the industry. Finally, the reliability of each component was assessed using Cronbach's alpha. The values of alpha were reasonably high at 0.812 for the first component (six items) and 0.768 for the second component (four items). Applying the same components to 2003 data, values of Cronbach's alpha were 0.717 for the first component and 0.803 for the second component.

Table 6.4 Barriers PCA- Rotated component matrix

	Technology commercialization barriers	**Bioproduct-specific barriers**
Lack of adequate product standard certification	**0.809**	0.115
Restrictions on IP rights	**0.801**	0.048
Lack of financial capital	**0.779**	0.099
Cost and timeliness of regulatory approval	**0.775**	-0.052
Difficulty in entering the commercial marketplace	**0.543**	0.074

Lack of skilled human resources	**0.540**	0.269
Unreliable quantity of biomass	-0.032	**0.849**
Unreliable quality of biomass	0.067	**0.839**
Higher transportation cost of biomass	0.159	**0.675**
Higher price of biomass	0.126	**0.662**
Percent variance explained	34.550	21.058
Cronbach's alpha	0.812	0.768

Strategies

The strategies question asked firms to rate the importance of a number of technology development and knowledge development strategies to their activities. The means and standard deviations for the items are shown in Table 6.5. A total of twelve items were included, and Cronbach's alpha was 0.800 for all items. As before, the "other" item was uncorrelated with the other item responses. After its deletion, alpha improved to 0.820. The highest ranked items were "entered product trials", "began new R&D project", and "acquired/used knowledge from industry sources".

Table 6.5 Importance of firm strategies to bioproduct development, 2006

	Mean	**SD**
Entered product trials/adapted products or processes for increased market penetration	3.60	1.312
Began new R&D project	3.30	1.420
Acquired and used knowledge from industry sources such as industry associations, competitors, clients and suppliers	3.24	1.386
Expanded into foreign markets	3.19	1.385
Developed/encouraged staff education/upgrading	3.17	1.119

Supply chain development	3.04	1.285
Acquired and used knowledge from public research institutions including universities and government laboratories	3.00	1.251
Used and updated databases of scientific information	2.82	1.233
Developed firm policies and practices for knowledge/IP protection	2.82	1.276
Conducted an IP audit to ensure protection of products and processes at all stages of development	2.48	1.265
Increased firm size through acquisition, merger or joint venture	2.40	1.384

Note: Mean responses for each item were not significantly different from 3.

The Kaiser-Meyer-Ohlin (KMO) measure of sampling adequacy was 0.726, which falls in the acceptable range. Bartlett's test statistic was 353.48, significant at the one percent level. Principal component analysis for the strategies question yielded three components with eigenvalues exceeding one. Overall, they accounted for 59.4 percent of total variation. While Cronbach's alpha for the first two factors was 0.774 and 0.722 respectively, it was just 0.560 for the third factor, which falls below the acceptable range. This indicates that internal consistency is low for this component and, as a result, it was dropped from the analysis. Table 6.6 shows heavily loaded items for the remaining two components.

The first component, comprised of five items, was focused on accessing external knowledge (from industry and government), using scientific databases, beginning new projects, and expanding into foreign markets. The overall theme of these items seemed to be the importance of external knowledge and markets, leading to "Accessing external knowledge and markets" as a name. New R&D project doesn't fit as neatly into that component, but it also does not load as well as the other items. The second component

includes just three items which reflect a focus on internal resources and knowledge development, resulting in "Developing internal knowledge and resources". The items—developing firm policies for knowledge protection, conducting an IP audit, and encouraging staff upgrading—all had factor loadings in excess of 0.6.

Table 6.6 Strategies PCA- Rotated component matrix

	Accessing external knowledge & markets	**Developing internal knowledge & resources**
Acquired and used knowledge from industry sources such as industry associations, competitors, clients and suppliers	**0.769**	0.138
Acquired and used knowledge from public research institutions including universities and government laboratories	**0.739**	0.25
Used and updated databases of scientific information	**0.668**	0.497
Expanded into foreign markets	**0.554**	-0.154
Began new R&D project	**0.531**	0.192
Developed firm policies and practices for knowledge/IP protection	0.206	**0.839**
Conducted an IP audit to ensure protection of products and processes at all stages of development	0.017	**0.739**
Developed/encouraged staff education/upgrading	0.411	**0.608**
Percent variance explained	37.397	12.066
Cronbach's alpha	0.774	0.722

The heavily loaded items for each component were used to construct multi-item scales, calculated as the average of responses to each of the heavily loaded items. The six multi-

item scales (two each for benefits, barriers, and strategies) were included in the regression analysis for 2006 and 2003. Table 6.7 shows the means and standard deviations for multi-item scales in each year. It is interesting to note that the mean of each scale (which is a measure of the importance of the factor) increased between the two years, albeit some—Cost/environmental benefits and Bioproduct-specific barriers—more than others. An increase in Cost/environmental benefits may reflect societal pressures for environmentally-friendly production and waste disposal. Bioproduct-specific barriers likely reflects the increase in biomass challenges faced by firms as they commercialize products; production requires a steady stream of biomass input which may be costly and/or difficulty to obtain for some firms.

Table 6.7 Summary statistics for benefits, barriers, and strategies multi-item scales, 2006 and 2003

	2006		2003	
	Mean	SD	Mean	SD
Product/sales benefits	3.768	0.968	3.758	1.158
Cost/environmental benefits	3.593	0.955	3.286	1.220
Technology commercialization barriers	2.790	0.933	2.767	0.918
Bioproduct-specific barriers	3.069	1.064	2.755	1.223
Accessing external knowledge & markets	3.126	0.966	2.967	0.984
Developing internal knowledge & resources	2.845	1.022	2.793	1.139

6.3 Regression results

The final variables included in the STATA regression analysis are shown in Table 6.8. Any transformations performed on the original variables are described in Appendix 1. Variables are also classified as representing internal, external, or market factors (or some combination thereof).

Table 6.8 Regression variables & transformations from survey variables

Variable	Regression variable(s)	Survey variables	Hypothesized relationship	2006 Mean	2006 SD	2003 Mean	2003 SD
Total product count	Totalproduct		NA	6.11	8.70	4.54	5.40
Internal							
IP	IP dummy[4]	IP=1 if one if firms held patent(s), 0 otherwise	+	0.33	0.40	0.31	0.46
Firm size	SmallFirm dummy	Smallfirm=1 if 1-49 employees, 0 otherwise	+/-	0.83	0.37	0.67	0.47
	LargeFirm dummy	Largefirm=1 if >149 employees, 0 otherwise	+/-	0.08	0.28	0.15	0.36
Experience	Years in BP (YRS)	Yrs_in_BP= firm age minus year firm began bioproducts activities	+	9.83	9.23	11.24	10.89
R&D	BP R&D spending/BP employees (BPRD)	BPRD=BP R&D/employees with BP responsibilities	+	604.44	4760.58	31.56	99.54
Strategic focus	EarlyFocus	EarlyFocus=1 if all products in development, 0 otherwise	-	0.25	0.43	0.21	0.41
	LateFocus	LateFocus=1 if all products	-	0.34	0.47	0.48	0.50

[4] Unfortunately, changes made in the IP question between 2003 and 2006 make it impossible to directly IP originating from different sources.

		on the market, 0 otherwise					
Relative importance of bps	BP_Importance	Revenues from bioproducts/total revenues	+	0.48	0.44	0.46	0.45
Strategic fit & resource challenges	Product/sales benefits	Multi-item scales for two benefits factors, two barrier factors, and two strategic factors from principal component analysis	+/-	3.77	0.97	3.76	1.16
	Cost/environmental benefits			3.59	0.96	3.29	1.22
	Technology commercialization barriers			2.79	0.93	2.77	0.92
	Bioproduct-specific barriers			3.07	1.06	2.75	1.22
	Accessing external knowledge & markets			3.13	0.97	2.97	0.98
	Developing internal knowledge & resources			2.84	1.02	2.79	1.14
Organizational structure	PrivateFirm	PrivateFirm=1 if the firm was privately owned, 0 otherwise	+/-	0.78	0.41	0.71	0.46
External							
SR&ED	SR&ED Dummy (SRED)	SRED=1 if firm applied for SR&ED tax credit for previous year	+	0.58	0.50	0.48	0.50

Collaborations	Number of collaborations (TotalCollab)	Count of number of collaborations	+	1.60	4.14	1.01	2.53
Accessing financial capital	TargetMet dummy	TargetMet=0 if firms raised 100% of the amount sought, 0 otherwise	+/-	0.20	0.40	0.19	0.39
	TargetNotMet dummy	TargetNotMet=0 if firm raised <100%, 0 otherwise	-	0.13	0.34	0.23	0.42
Market							
Competitive environment & nature of market	Subsector: biofuels (Biofuel)	Firms coded by *primary* development (dummy variable if firm is mainly developing in that subsector)	+ chemicals - fuels	0.26	0.44	0.28	0.45
	Biochemicals (Biochem)			0.16	0.37	0.27	0.44
	Biofibre (Biofib)			0.09	0.28	0.12	0.32
	Other (Bioother)			0.40	0.49	0.19	0.39
Regional effects	Regional dummies: Quebec	Dummies coded for each area, directly from region variable	+/-	0.28	0.45	0.31	0.46
	Atlantic			0.06	0.24	0.07	0.25
	Prairies			0.14	0.35	0.11	0.32
	Alberta			0.11	0.31	0.12	0.32
	BC			0.20	0.40	0.17	0.37

For dichotomous variables, the means necessarily fall between zero and one. It is interesting to note that while the average products per firm increased between 2003 and 2006, the median number was three for both years. This implies that the distribution for the dependent variable had a greater rightward skew in 2006 than in 2003. BPRD also showed greater variability in 2006 than the previous survey year; as the variable represents bioproduct R&D spending per bioproduct employee, it will necessarily rise if R&D spending rises, if the number of bioproduct employees falls, or some combination of these effects. As with the total product count, the medians were much closer in value than the means, at 5.71 in 2006 and 3.23 in 2003.

Before turning to the estimated coefficients, note that a Likelihood Ratio Test was used to determine the joint significance of each group of factors—internal, external and market—for 2003 and 2006. Each group of variables had jointly significant parameter estimates both years at the five percent level or better; interestingly, internal and external categories have both become more highly significant between 2003 and 2006, while market factors have become slightly less significant. This might indicate that firms' innovation patterns are becoming more dependent on successful management of their resource mix than on the conditions of their subsector or region.

Results from the negative binomial regression are presented in Table 6.9. The regression uses sampling weights provided by survey methodologists which account for sampling design (i.e. the inverse of the probability of a firm being selected) and non-response. Because the weights were incorporated at the time of the regression, STATA

automatically provides robust estimates and standard errors. The regression uses STATA's default variance dispersion, which corresponds to the Cameron and Trivedi's (1986) NB2 model and allows the variance to increase with the conditional mean of the dependent variable.

The table provides coefficient estimates and standard errors for the 2006 and 2003 regressions. Marginal effects are included to facilitate the interpretation of coefficient magnitudes and relative importance of regressors; as there are no interaction terms, the signs of marginal effects are identical to the coefficient signs. These marginal effects represent the change in the dependent variable, TotalProduct, for a one unit change in the independent variable measured at its mean (note that for dummy variables, the marginal effect is for the change from zero to one). This is normally a reasonable approximation of the average marginal effect (Greene 2000). Wald statistics testing the null that the coefficients are jointly equal to zero are 256 and 388 for the 2006 and 2003 models respectively; with 28 degrees of freedom this joint null is rejected at the one percent level.

Table 6.9 Regression results: NB2 regression of Total Product Count 2006 & 2003

	2006		2003	
	Robust coef B	**Marginal effect dy/dx**	**Robust coef B**	**Marginal effect dy/dx**
Constant	0.505		1.40***	
	(0.739)	NA	(0.475)	NA
	Internal			
IP	0.548**	2.37**	0.117	0.415
	(0.225)	(1.11)	(0.121)	(0.434)
Smallfirm	-0.465*	-2.14	-0.531***	-2.03***
	(0.248)	(1.32)	(0.153)	(0.663)
Largefirm	-0.0738	-0.280	0.224	0.838
	(0.373)	(1.37)	(0.236)	(0.963)
Yrs_in_BP	0.007	0.027	0.007	0.023
	(0.009)	(0.035)	(0.004)	(0.015)
BPRD	2.00×10^{-5}***	9.00×10^{-5}***	-5.60×10^{-4}*	-1.93×10^{-3}*
	(0.000)[a]	(0.000)[a]	(0.000)[a]	(0.001)
EarlyFocus	-0.227	-0.840	-0.681***	-1.975***
	(0.244)	(0.851)	(0.159)	(0.390)
Late Focus	-0.368	-1.36	-0.775***	-2.70***
	(0.268)	(0.939)	(0.136)	(0.489)
BpImportance	1.05***	4.12***	-0.169	-0.584
	(0.209)	(0.838)	(0.141)	(0.486)
Product/sales benefits	-0.063	-0.248	0.151***	0.521**
	(0.094)	(0.369)	(0.057)	(0.205)
Cost/environmental benefits	0.305***	1.19***	-0.0847	-0.293
	(0.114)	(0.462)	(0.054)	(0.186)
Technology commercialization barriers	-0.085	-0.333	0.061	0.210
	(0.090)	(0.348)	(0.082)	(0.282)
Bioproduct-specific barriers	-0.086	-0.337	-0.0268	-0.093

	(0.083)	(0.325)	(0.047)	(0.164)
Accessing external knowledge & markets	0.175**	0.684**	-0.0844	-0.291
	(0.748)	(0.287)	(0.086)	(0.299)
Developing internal knowledge & resources	-0.180*	-0.704*	0.020	0.068
	(0.095)	(0.381)	(0.058)	(0.202)
PrivateFirm	0.754***	2.44***	-0.0245	-0.085
	(0.220)	(0.619)	(0.126)	(0.441)
		External		
SRED	-0.275	-1.10	0.391***	1.37***
	(0.196)	(0.795)	(0.124)	(0.451)
TotalCollab	0.031*	0.119*	0.0722***	0.249***
	(0.016)	(0.062)	(0.0210)	(0.0730)
TargetMet	-0.510**	-1.73**	0.0184	0.0638
	(0.252)	(0.746)	(0.150)	(0.526)
TargetNotMet	-0.184	-0.672	0.121	0.433
	(0.279)	(0.955)	(0.143)	(0.531)
		Market		
Biochem	0.823***	4.38**	0.440***	1.70**
	(0.296)	(2.11)	(0.164)	(0.716)
Biofuel	-0.594**	-2.04**	-0.215	-0.710
	(0.276)	(0.866)	(0.211)	(0.666)
Biofib	-1.39***	-3.31***	-0.304	-0.939
	(0.326)	(0.530)	(0.216)	(0.594)
Bioother	-0.036	-0.141	-0.157	-0.517
	(0.256)	(0.993)	(0.190)	(0.594)
Atlantic	-0.171	-0.620	-0.299*	-0.909*
	(0.328)	(1.11)	(0.171)	(0.472)
Quebec	0.057	0.224	0.233	0.842
	(0.211)	(0.845)	(0.143)	(0.549)
Prairie	0.707**	3.64*	0.453**	1.88**
	(0.293)	(1.979)	(0.188)	(0.933)

Alberta	-0.330	-1.14	0.525***	2.25**
	(0.270)	(0.833)	(0.198)	(1.044)
BC	0.038	0.146	0.219	0.816
	(0.259)	(1.033)	(0.185)	(0.747)
Over-dispersion parameter alpha	0.194***		0.142***	
	(0.050)		(0.037)	
Number of observations[b]	239		232	
Log pseudolikelihood	-554.0		-496.4	
Wald chi-square	256.48		387.73	
Prob>chi2	0.000		0.000	

Standard errors are presented in parentheses.

*,**,*** denote significance at the ten percent, five percent, and one percent levels.

[a] Standard error less than 0.000

[b]Number of observations is the effective number, based on sample weights. Because of Statistics Canada's guidelines, sample sizes may not be disclosed.

The first regressor, the intellectual property dummy variable IP, was significant at the five percent level with a coefficient of 0.55. As IP includes not only property rights issued for the firm's own technology (internal) but those acquired from other firms, the coefficient reflects the impact of holding the rights for a given technology. Changes in survey construction between 2003 and 2006 made it difficult to distinguish between IP which was owned vs in-licensed, or the jurisdiction of the IP (e.g. Canadian Intellectual Property Office, etc), which may have an effect on how important IP is to innovation. Nonetheless, the marginal effect suggests that in 2006, a firm with intellectual property protection on the technologies it used was expected to have 2.37 more products than an otherwise equal firm with no IP rights. While the coefficient (and corresponding marginal effect) in 2003 were also positive, the estimate is not significant at the ten percent level or better.

Table 6.10 provides further support for the importance of intellectual property to innovative activity. In both 2003 and 2006, fewer than half of all firms held some form of IP rights. However, in both cases, these firms also had an above average number of products. In 2006, firms with IP averaged 1.3 products more than those without, while in 2003 the difference is even more marked with 2.73 products between them. It is also worth noting that the proportion of firms with IP rose between 2003 and 2006. That said, while both groups were developing more products in 2006 than 2003, the average number of products for firms without IP rose 53 percent over the period.

Table 6.10 Average count of products under development and in production, 2006 & 2003, by intellectual property

	2006		2003	
	Mean product count	Firms	Mean product count	Firms
Did not have IP	5.67	159	3.70	161
Owned/licensed IP	6.97	80	6.43	72
Total	6.11	239	4.54	232

In controlling for firm size effects in innovation, medium-sized firms (50-149 employees) served as the omitted group, with dummy variables for small and large firms. As indicated in Table 6.9, the coefficient on the large firm dummy variable is not significant. Moreover, the marginal effects are also not significant, suggesting no difference in the count of the number of products between large and medium sized firms. While the coefficient on the small firm dummy variable is significant at the ten percent level in 2006, the marginal effect is not statistically different from zero suggesting no difference in the count between small and medium firms for that year. In 2003 however, small firms were expected to have 2.2 products fewer than medium firms, a result significant at the one percent level. This is consistent with the observation in Table 6.11 that the average number of products for small firms rose from 3.70 in 2003 to 6.42 in 2006. Large firms had substantially fewer products that medium or small firms in 2003 according to Table 6.11, but as the result is not statistically significant in the regression model, the discrepancy may be largely accounted for by other factors. Additionally, as the number of medium and large sized firms in 2006 was modest and a few medium sized firms had very high product counts, it may be that the number of observations resulted in insufficient evidence for statistical significance.

It is also interesting to note that medium and large firms tend to focus on products which are closer to market; compared with small firms, who had 54.7 percent of products on the market, medium firms had 78.6 percent on the market, while large firms had 69.3 percent. It is likely that the largest firms are narrowing their focus to a few main products which are close to or on the market. Product success depends on the firm's quality of production, marketing and technical activities, which depend on firm resources (Calantone and di Benedetto 1988). Capacity also becomes an issue: the larger firms typically employed 701 individuals in 2006, but only 75 (10.6 percent) were engaged in bioproduct activities. This is consistent with the notion of bioproducts as a secondary activity for many of these firms, and also that they have production capacity available due to their primary production processes. Small firms, by contrast, typically employed just 14 individuals, but 7 worked with bioproducts. While it is not always the case, it is often true that these firms have specialized knowledge and are highly skilled at performing research and development functions which require less capital assets.

Table 6.11 Average number of products under development and in production in 2006 and 2003, by firm size

	2006	2003
Firm size	Average products per firm	
Small (<50 employees)	6.42	3.70
Medium (50-149 employees)	6.94	5.59
Large (>149 employees)	2.01	6.99

Yrs_in_BP indicates the number of years of firm involvement in bioproduct activities (which may differ from firm age). It was not significant in either year, though the

coefficient was positive for both 2003 and 2006. While experience in the bioproduct industry may help firms to have a large number of products, it is likely that they can compensate via experience in biotechnology or another similar industry, knowledge acquired from human capital, etc. It is not imperative for a firm to have a significant amount of time developing bioproducts so long as they have the skills and resources.

BPRD represents Bioproduct R&D spending per bioproduct employee. Both the coefficient of 0.00002 and marginal effect of 0.000093 were significant at the one percent level. Because R&D is measured in thousands, this implies that a firm would be expected to have one additional product for roughly each $10,753,000 in bioproduct R&D spending per bioproduct employee. While the relationship is significant, it would appear that increasing R&D expenditures within a moderate range will not result in greater innovative activity. The 2003 regression indicates a negative effect, with the coefficient of -0.00056 and marginal effect of -0.0193, both of which were significant at the ten percent level. Although this may seem confounding, it is not altogether surprising. In other technology sectors, the relationship between R&D and product development can be complex; while investing in R&D can increase innovation, the relationship often relies on a host of other factors. The factors, coupled with the dynamic, evolving nature of Canada's bioproduct industry, suggest the fragility of this result with respect to BPRD is not unexpected.

Dummy variables for firms focusing on early and late stages of the development process were both significant at the one percent level in 2003 with magnitudes of -0.68 and -0.76.

The marginal effects in that instance were -1.97 and -2.70 for early and late focused firms respectively, indicating that firms who specialized in one area of the process were likely to have fewer products than those with activities across the broader continuum. While the estimates were not significant in 2006, they were also negative for both stages. These results should not be surprising, and indeed are consistent with the initial hypotheses. Firms focused only on late stage bioproducts are not in the development business and can be expected to have fewer products on the market. Early stage firms are unlikely to have the resources for managing numerous products under development as they receive no income from producing and marketing the end products. The resources to fund bioproduct development must come from financing initiatives or from selling or licensing the bioproducts they develop. They are also reinforced by Table 6.12—it is evident that for both years, firms with either an early or late focus had fewer products than the overall mean.

Table 6.12 Average count of products under development and in production, 2006 & 2003, by early/late focus

	2006			2003		
	Mean product count	Firms	%	Mean product count	Firms	%
Early focus	2.37	59	24.69	3.12	50	21.55
Late focus	4.57	81	33.89	3.05	111	47.85
Comprehensive focus	9.65	98	41.42	7.81	72	30.60

BP_Importance, measured as revenues from bioproducts divided by total revenues, was included to reflect the relative importance a firm places on its bioproduct activities. This

would seem relevant as most firms have non-bioproduct activities in addition to their bioproduct efforts. The coefficient of 1.05 for BP_Importance was highly significant in 2006, and had one of the highest marginal effects at 4.11. (Note that this is for a one-unit change in BP_Importance, however the variable is a ratio which can only range from zero to one.) The extent of the firm's focus on bioproduct activities (reflected by sales) relative to other activities may therefore help predict their innovative success in terms of product counts.

Multi-item scales derived from factor analysis of benefits, barriers, and strategies questions were used to construct two "variables" for each question, as discussed earlier. These were calculated as the unweighted average of the Likert scale ratings for each of the heavily loaded items in the component. In 2003, the importance of Product/sales benefits had a positive coefficient of 0.15, significant at the one percent level. The corresponding marginal effect of 0.52 was significant at the five percent level. This captured a desire to increase product range, performance, or expand sales and market share, but implies that this dimension would have a limited impact overall, as range of possible responses was only from one to five. However, in 2006 the coefficient of 0.30 for Cost/environmental benefits was significant at the one percent level with a marginal effect of 1.19. This implies that firms who rated benefits relating to the environment, reduced production cost/energy consumption, and community development as more important were expected to have more products. Firms who develop bioproducts in order to reduce internal costs—through using an output from another production process, for example—may be more innovative than those which have the technological capacity but

need to deal with obtaining their biomass elsewhere or selling and marketing products to other firms or consumers. Similarly, many firms who rated environmental benefits as fairly high may have costly waste products from their primary production process and be under pressure from government, shareholders, and the community to lessen their environmental impact.

Neither of the two barrier variables was significant in either year, although the coefficients were negative for both in 2006. It was expected that firms with high perceived barriers to development would have fewer products; those firms with great innovation success either did not experience substantial innovation hurdles or were able to deal effectively with them. However, the fact remains that the perceived importance of barriers—bioproduct related as well as traditional technology development—did not affect the number of products a firm had in its portfolio.

Finally, coefficients for both strategy variables were highly significant in 2006. Accessing external knowledge & markets, which focused on accessing resources through other firms, government, and information databases as well as expanding into foreign markets, had a coefficient of 0.17 and a marginal effect of 0.68. It would thus appear that firms which are able to make effective use of external resources are able to develop more products. Developing internal knowledge & resources, reflecting a more internal focus on IP protection and employee development, had a negative coefficient of -0.18 and a marginal effect of -0.70. A focus on developing IP and internal resources may indicate a focus on a limited set of bioproducts. While development of internal resources is

important also, being able to make use of information from other sources and be aware of new market opportunities may help firms develop a more robust portfolio of technologies and products. Another possibility is that firms with just a few products are focusing their efforts on development of internal abilities in an attempt to expand their portfolio in the future.

The dummy variable Privatefirm was included to determine if there is a relationship between the innovation and the firm's governance. This proved to be the case, at least for 2006: The coefficient of 0.75 is significant at the one percent level, with private firms expected to have 2.44 more products than public ones. There was no such effect present in 2003. One explanation for this result is similar to that of financing. The ownership of a closely held firm typically has more knowledge regarding the sector and technology, and has more information than public investors (due to reduced risk of disclosure), so the firm may differ in their product pipeline. Going back to the conceptual framework, the project selected by management may differ based on the firm's ownership; for a public company, investors may diverge from managers or entrepreneurs in terms of their investment horizon, their access to information, and their knowledge of the industry—in short, what they perceive as a "good investment" may be substantially different.

The coefficient on the dummy variable indicating Scientific Research & Experimental Development tax credit use was significant in 2003 only, with a value of 0.39. The marginal effect was 1.37, a result significant at the one percent level. However, firms using the credit in 2006 were not expected to have significantly more products; the

coefficient, while not significant, was actually negative. Further, Table 6.13 shows the average number of products in 2003 and 2006 for firms using and not using the SR&ED credit in that particular year. In both instances, firms using the credit had fewer products than those without. One possible explanation for this is that firms with several smaller products require less R&D investment and intensity compared with those developing one or two major technologies. This can be especially true when the technology is developed from basic research stage through production. For those firms focusing on mid to late stage technologies, there may be little need for R&D investment--and thus limited opportunity to use of the program.

Alternatively, firms which had several products in research stages in 2003 may have since brought those products to market, implying that may still carry a large number of products but currently use the tax credit. With 60 percent of all products on the market, this scenario is distinctly possible. Still, it is interesting to note that usage of the program increased roughly 10 percentage points between 2003 and 2006. Finally, the question asks for tax credits applied for in 2006, which would reflect activities in the year 2005 and thus not necessarily match up with 2006 activity. In order to determine the true effects of this particular program on innovative activity, it would be useful to track SR&ED use over time compared with innovative activity represented by products, R&D, patents, and revenues or profits to determine whether it is making a substantial difference.

Table 6.13 Average count of products under development and in production, 2006 & 2003, by use of SR&ED tax credit

	2006			2003		
	Mean product count	Firms	%	Mean product count	Firms	%
Used SR&ED	5.74	137	57.32	3.29	110	47.41
Did not use SR&ED	6.60	101	42.26	5.91	122	52.59

The variable representing the number of collaborative arrangements, TotalCollab, had a coefficient of 0.03 in 2006, significant at the ten percent level. Since this is a numerical variable rather than dichotomous, the marginal effect of 0.12 refers to the increase in expected product count given an increase in the number of collaborations by one. Further, the number of collaborations was highly significant (one percent level) in 2003, with a coefficient of 0.072 and a marginal effect of 0.25. Thus, a firm with four collaborations would be expected to have an additional product when compared with another identical firm with no collaborations. This finding confirms the expected result that collaborations do facilitate innovation, especially in terms of the number of products under development and on the market. Going back to the conceptual framework, this implies that innovation is facilitated and increased by the firm's ability to leverage its own competencies by accessing resources of other firms, government, and university agents in a research or development capacity, and is consistent with previous work in the biotechnology sector (Powell et al. 1996).

Two variables were included in an attempt to capture some aspect of the innovation-financing relationship. This relationship is necessarily complex: firms pursue financing for different reasons, and at different times in the development process. The ability to

succeed depends not only on investors' evaluations of the technology and its potential returns, but also market conditions and a host of other factors. With data from only two surveys and relatively small sample sizes in each case, this analysis categorizes financing outcomes into three possibilities. First, firms may choose not to seek financing during the survey year. This is considered the omitted group. Firms choosing to seek capital are categorizes as either succeeding or failing. The model simply classifies firms as being entirely successful—meaning they achieved 100 percent of their capital target—or being partially successful or unsuccessful—meaning they achieved less than 100 percent of their target.

The only significant result from the financing variables was for TargetMet. The coefficient for TargetMet is -0.51 for 2006. Interestingly, firms which attempted to raise capital and were entirely successful are expected to have 1.73 fewer products in 2006 than firms which did not attempt to raise capital. A possible explanation is that firms need to be able to communicate their technology platforms and their market value to potential investors. If this rests on a small number of high-value technologies, especially those close to market, it may be easier for firms to obtain capital. However, these results imply that a more focused analysis of the issues surrounding financing and its implications needs to be undertaken in order to achieve a fuller understanding of the role of financing in innovative success.

In order to examine and control for possible differences in product counts by subsector, firms were classified based on their primary bioproduct type and corresponding dummy

variables were created. Firms focusing primarily on biocontrol (pesticides, fungicides, herbicides) served as the omitted group as they had the median number of products across subsectors in 2006; further, they were closest to the mean in 2003. Bioproduct type dummy variables were included for firms focusing on biofuels/bioenergy, biochemicals, biofibres, and other bioproducts. Compared with the omitted category, firms focusing on biochemicals (Biochem) had significantly more products in 2006, and biofuels/bioenergy (Biofuel) and biofibres (Biofib) had significantly fewer. Coefficients were 0.82 for Biochem, significant at the one percent level; -1.39 for Biofib, also significant at the one percent level; and -0.59 for Biofuel, significant at the five percent level. Turning to marginal effects, biochemical firms were expected to have 4.38 more products—this is clearly supported by Table 6.14, where biochemical firms averaged 11.11 products in development and/or on the market in 2006 compared with the mean of 6.11 products. Biofuel/bioenergy and biofibre firms were expected to have 2.04 and 3.31 products less, respectively, than the biocontrol firms. These two subsectors had the fewest products in 2006. Firms primarily developing other bioproducts did not differ significantly in the number of products they had—although they averaged noticeably more than biocontrol firms in 2006 (7.82 compared with 4.66), it would appear that this difference is accounted for by other controlling variables. Of the 2003 subsector dummy variables, only the coefficient on Biochem of 0.44 was significant (at the one percent level). As with 2006, biochemical firms were expected to be developing/producing more bioproducts; 1.70 more according to the marginal effect.

Table 6.14 Average number of products under development and in production 2006 and 2003, by primary bioproduct type

	2006		2003	
	Mean product count	Firms	Mean product count	Firms
Biofuel/bioenergy	2.52	38	3.85	67
Biochemical	11.11	23	6.66	61
Biofibre	2.06	23	2.83	27
Biocontrol	4.66	62	4.35	33
Bioother	7.82	93	3.86	45
Total	6.11	239	4.54	232

As with size, region was expected to play a role in explaining product innovation. These impacts may also change with time due to the emergence and growth of regional innovation networks and regional incentives for the development and production of bioproducts. In 2006, firms in the Atlantic region and Alberta were substantially below the mean number of products with 2.26 and 3.04 (Table 6.15), while firms in British Columbia and the Prairies (Manitoba and Saskatchewan) were above the mean with 7.50 and 9.47. In 2003, the distribution across regions was tighter, with average product counts being closer to the mean of 4.54 products. Firms in Alberta and Atlantic provinces were the only ones whose average number of products declined from 2003 to 2006.

Table 6.15 Average count of products under development and in production, 2006 & 2003, by region

	2006		2003	
	Mean product count	Firms	Mean product count	Firms
Alberta	3.04	25	5.39	27
Atlantic	2.26	14	2.93	15
British Columbia	7.50	48	4.40	39
Ontario	6.15	52	3.24	53

Prairie (Man/Sask)	9.47	33	5.81	27
Quebec	5.38	66	5.12	72
Total	6.11	239	4.54	232

Dummy variables were included for firms located in Atlantic, Quebec, Prairie, Alberta, and BC regions with firms located in Ontario left as the omitted category for each year. The regression results support the previous observations. The Prairie firms were expected to have more products than Ontario firms, with a coefficient of 0.71, significant at the five percent level. The marginal effect, significant at the ten percent level, is 3.64. Firms in the Prairie region also had significantly more products than Ontario firms in 2003. This region was one of only two in which the number of firms actually increased between 2003 and 2006. The higher number of products may also reflect the relative availability of agricultural biomass in the region. British Columbia, which had the second highest average product counts in 2006, was the other region with growth in the firm population and arguably the other region with access to biomass (most commonly forestry residues). None of the estimates for the Atlantic, Quebec, Alberta or British Columbia firms were significant in 2006. In 2003, Atlantic firms were expected to have fewer products than Ontario firms with a coefficient of -0.30 and a marginal effect of -0.91; Alberta firms were expected to have more products, with a coefficient of 0.53 and marginal effect of 2.25.

With respect to the marked differences between 2003 and 2006, it is important to first note that there was substantial turnover, such that the sample of firms in 2006 was largely different from that of 2003. This occurred as a result of the nature of the industry; the

same industry entry and exit can be seen in pharmaceutical biotechnology, though to a lesser extent because the industry is older and more established. When the success of a given firm is contingent on a particular product or technology platform, failure in trials or on the market can mean the end of the firm. Also, the sample size was smaller in 2006 than 2003 due in part to non-response. While weights are constructed to try and minimize this influence, it is still the case that individual outliers can have a strong effect on the overall sample. These two effects may account in part for the some of the unexpected discrepancies between 2003 and 2006, and thus it is important to keep these in mind while comparing regressions and descriptive statistics between survey years.

6.4 Conclusion

The factor and regression analysis presented above suggests some interesting conclusions. Main results can be contextualized in terms of the importance of internal and strategic, external, and market factors in facilitating innovative activity. These conclusions can help explain product innovation, and provide information for policy makers aiming to encourage commercialization of bioproducts.

Internal factors and characteristics help explain innovation via firm size and intellectual property. R&D has a positive relationship with product counts, but increasing R&D within a modest range does not appear to drive innovation. This is consistent with previous findings that R&D outlays are not always the best measure of innovative output;

while they communicate intent to produce innovations, they are not necessarily a strong predictor of innovative success. Small firms tend to have fewer products than other firms, likely because they can only take on so many projects. Interestingly, large firms did not have significantly more products than medium firms, implying that beyond a certain point scale—at least in terms of employees—is not a deciding factor. This may also be partly explained by the fact that for many large firms producing bioproducts is a secondary activity, often as a result of byproducts. Firms seem better off if they can protect their technology; while IP is not the only way of doing this, it can add substantial value and allow for technology transfer and licensing. In terms of the portfolio, holding patents may allow firms to broaden their focus to more projects by ensuring the protection of their existing technology and reducing the risk of inadvertent disclosure. It is possible that the type of IP matters—e.g. the licensing office, or whether it belongs to the firm or is in-licensed. For these two surveys, it is impossible to include this aspect because of changes in the IP question. However, it would be worth investigating whether benefits differ based on whether the IP is Canadian, American, European, etc, and whether it is owned or licensed, as this would shed light on the relative value of IP from various sources.

Strategic factors such as the relative importance of bioproducts to the firm (defined as revenues from bioproducts divided by total revenues) seem to be important predictors of the number of products. In 2006, firms which derived all of their revenues from bioproducts were expected to have 4.12 more products than if they had no bioproduct revenues. While this assumes the firm has some bioproducts on the market, this is not an

unreasonable assumption in the bioproducts industry where most firms have multiple products and the majority of products are on the market. This result confirms the idea of strategic focus in that firms devoting a greater proportion of their resources to bioproduct development, production and sales tend to have more bioproducts overall. Further, firms focusing only on early-stage or late-stage development seem to have fewer products, a result strongly supported in 2003 though less so in 2006. The number of firms in this situation has fallen, since more firms are now taking a comprehensive approach—it may be that firms are better able to take part in all areas of the development process and fill in weaknesses by accessing external knowledge or capacity. The ability to "extend" firm capacity via collaborations and contracts allows for this participation from basic research to production. Private firms also tended to have more products in 2006, which may be a result of information asymmetry and disclosure issues. While perceived product benefits seemed to encourage firms to innovate in 2003, cost and environmental benefits were found to have a greater impact in driving innovation in 2006. It may be that firms are following others in going green, and being encouraged by shareholders, the community, etc to support sustainable development. Alternatively, it could be that firms initially were looking to capitalize on consumer demand and government incentives for greener products, but as more technologies are being commercialized, firms are seeing the value in their own production processes and communities. The result that firms responding to reduced production cost may lend support for the Porter hypothesis (1991), which supposes that regulation can act as an incentive to innovate, and help firms improve their efficiency through such innovation. In terms of strategies, firms who found accessing external resources important were more innovative than those focusing primarily on their

own resources. This is entirely consistent with earlier conclusions that firms able to complement internal resources by accessing collaborations and other capacity have more products in their portfolio.

Market and exogenous factors such as subsector and region also have an influence. Subsector is one of the most substantial predictors of the number of products because there is such a variety of bioproducts, each with a slightly different development process. Firms involved in biochemical production tend to have more products, while biofuel and biofibre firms have less, likely owing to the additional resource intensiveness required to develop and produce these types of products. Because of these differences, it is not always possible or even desirable for a firm to have a high number of products; innovation measured by product count must be examined in the context of the subsector in which the firm is operating. When designing policies to encourage innovation it will be important to bear this in mind. Regional results were somewhat more disparate across survey years. It is difficult to examine such effects when there are only a small number of firms in each area. However, firms in Manitoba and Saskatchewan tended to have more products across both years. It is likely that regional differences may result from the availability of biomass and other resources for firm with products closer to market, while regional innovation networks may play an important role for those in earlier stages. However, the role of market factors appears to be diminishing when compared with the importance of internal and external characteristics and resources.

Collaborations were the most clear-cut influence of the external factors. Collaborations clearly have a positive impact on the number of products by allowing firms to leverage their own competencies while accessing complementary resources in other firms, labs, and academia which act to encourage innovation. Financing requires a more in-depth analysis. Many firms have enough capital internally that they do not need to raise funds. For those firms that do, the relationship with innovation may be more complex; as with the Privatefirm variable, the explanation for the negative effect here may go back to the ability to communicate technology to investors. The SR&ED credit, significant in 2003 only, does not appear to be encouraging product innovation in the current period. While this type of policy is traditionally effective in lowering the marginal cost of R&D and thus increasing expenditures (Lehto 2008), it may have limited effectiveness if R&D itself is not a major contributor to innovative success.

Firms with collaborations, intellectual property, R&D, a focus on accessing external resources, and a focus on bioproducts tend to have a broader innovation portfolio. Overall, this appears consistent with the resource-based view in that firms who strategically manage their internal and external resources seem better able to innovate. A narrow development focus (early or late stage only), focusing on internal resources alone, or having small firm size tend to reduce the number of products. Region and subsector also play a role by imposing certain limitations or providing unique opportunities, but this role may be diminishing as firms depend more on access to resources than market conditions and regional factors.

7 Conclusion

7.1 Introduction

The previous chapters of this study have investigated characteristics and resources which influence firm level bioproduct innovation. A conceptual framework for selecting projects has been developed using the resource-based theory of the firm. Subsequent chapters build on this framework to develop an econometric count data model for assessing determinants of innovative activity. The model, along with factor analysis of firm benefits, barriers, and strategies, provide insights for firms and policy makers as to the importance of distinct internal, external and market characteristics and their role in influencing product innovation. This chapter reviews those findings and discusses the implications for firms and policy, and provides a number of recommendations for future research.

7.2 Summary

Preceding chapters address the objectives as outlined in Chapter 1. Criteria and characteristics thought to be relevant to innovation have been grouped into internal, external, and market characteristics, and hypotheses developed based on the biotechnology and innovation literature, in addition to unique industry factors. Factors derived from other literature include firm size, R&D expenditure, intellectual property, collaborations, financing success, experience, policy, ownership, and firm strategy. Other factors introduced include dummy variables for region and bioproducts type, as

well as for firms with either an early or late development focus, and a variable for the relative importance of bioproduct development to the firm's overall activities. These characteristics were used as explanatory variables for the subsequent regression and factor analysis.

The overall structure of the Canadian industry has been discussed in the context of the 2003 and 2006 Bioproducts Development Surveys in Chapter 3. While the size of the bioproduct sector is still modest—239 firms with revenues of $1.76 billion—it is evident that the sector is evolving. While overall bioproducts revenues fell in absolute terms, bioproducts revenues per employee rose 11 percent. Also important to note are the significant growth in the average number of products per firm between the two years, the increasing dominance of small firms in the sector (exemplified in part by the 27 percent growth in the small firm population compared with decline in the number of both medium and large sized firms), and the continued focus on use of agricultural and forestry biomass. The domestic availability of these inputs places Canada in a strong position to take advantage of future growth of the bioeconomy.

Turning to factor analysis, two main dimensions are identified on each of the Likert-scale questions asked in the Bioproducts Development Survey. These dimensions are product/sales benefits and cost/environmental benefits, technology commercialization barriers and bioproducts-specific barriers, and accessing external knowledge and markets and developing internal knowledge and resources. Each of these dimensions reflects a particular perspective or motivation which reflects in turn on the resources of the firm.

A growing importance is being placed on bioproduct specific barriers and cost/environmental benefits; cost/environmental benefits and accessing external knowledge both have a significant positive relationship with innovative activity measured as the number of products in 2006. This implies that those firms with a strong understanding of their internal competencies and an ability and willingness to access complementary external resources have broader innovation portfolios, supportive of the resource-based view of the firm. Other factors of importance are intellectual property, the number of collaborations, private ownership, relative importance of bioproducts, the subsector (with biochemical firms tending to have more products while biofuels and biofibre firms have less), and the region (with firms in Manitoba and Saskatchewan having more products).

7.3 Implications for industry and policy

This research yields important insights for firms, industry organizations, policy makers, and future research. First, protection of intellectual property is clearly an important determinant of innovative activity. Patents provide a means of capturing value arising from the direction of firm resources, and may indirectly help firms secure financing (especially in the case of small firms by providing cash flow via selling or licensing). Initiatives which improve or encourage IP sharing (via out/in-licensing, sales, etc.) often benefit both parties, leaving each of them free to focus on their core strengths which translates into greater profits and shorter time to market. Because some firms are limited in their internal resources, accessing external capabilities can play an instrumental role in

facilitating development. This research shows that those firms wishing to develop or support an extensive product portfolio should focus on accessing such external knowledge. As with IP, this allows the firm to focus on its strengths while supplementing its internal activities with outside knowledge and other assets. Policy makers should pursue tools which facilitate networking and collaborations between firms in order to maximize this effect.

R&D does not demonstrate a clear relationship to commercialization or innovation—as noted earlier, basic research in particular adds to the base of scientific knowledge and can create spillovers. However, if the goal for policy makers or firms is to get products to market, it may be that their time is better spent pursuing prototype development or other late-stage work (Rothwell 2007). Further, bigger is not necessarily better when it comes to innovation: though small firms may have fewer products due to resource constraints, the effect of scale disappears entirely, as indicated by the result that large firms did not have significantly more products than medium firms.

While focusing on one part of the development process is not a drawback, firms with the most products tend to be involved in the full research-to-production spectrum. Further, this approach seems to have its benefits, as the proportion of firms engaged in both R&D and production has risen compared with those specializing. Also, those firms who are more focused on bioproducts (vs their other activities) tend to have more bioproduct innovations.

The unique nature of the bioproduct sector implies that some particular aspects need to be considered from both the industry and policy perspectives. Firms are showing increasing awareness of the cost and environmental benefits arising from their activities. This is an important consideration for policy makers, as it aids in understanding the motivation of firms in developing bioproducts. The reduction in importance of product and sales benefits relative to cost and environmental benefits could mean that policy makers will need to focus on different tools in order to capitalize on the incentive for firms. However, this shift is also in line with the changing priorities of governments who are also increasing their emphasis on the environment. Bioproducts are important to both policy makers and industry. There is also an increasing focus on bioproduct-specific barriers—this may prove to be an issue in the coming years, and should be noted by policy makers.

Finally, it is important to consider the effects of policy on any given subsector or type of bioproduction. For instance, those firms developing biofuels may be able to take advantage of research grants more extensively than a biofibre or bioplastic firm which might spend relatively more time and resources developing prototypes. Region will also continue to play a role due to available supply of biomass, localized economic conditions, emergence of regional innovation networks, and provincial legislation and incentives for development.

7.4 Limitations

Due to the emergent and dynamic nature of the bioproduct industry and the fact that few studies have examined it thus far, it is difficult to assess generalizability of results. Clearly, the survey results indicate substantial differences in firm characteristics and activity trends between 2003 and 2006, however it will take time and additional research to know if these changes are truly reflective the direction the sector will take in the coming years. In addition, the sample sizes are relatively small (reflecting in part that the sector itself is limited to a few hundred firms across Canada) and the firms diverse in their activities, limiting some of the conclusions which might be drawn.

Additionally, changes in survey questions between the two period limit the type of analysis that can be performed across years. The intellectual property question falls into this category. Once the survey has been conducted in more periods and the questions are stabilized, this issue will be addressed. In the meantime, analysis of the current year of survey data cannot be compared to other years without making certain compromises regarding the depth of the investigation.

In terms of the regression analysis, innovative activity has been measured as the number of products under development and in the market. Clearly this does not capture the entire spectrum of innovative activity, nor does it distinguish between innovations of different importance or scale. As discussed earlier, the reason for fewer products amongst firms producing biofuels or biofibres compared with biochemicals is likely due to the resource intensity required to develop a single product. The devotion of time, capital, and

knowledge to bring one bioenergy product to the stage where it is ready for full production will clearly exceed that of a biochemical or biocatalyst in most instances. Data availability is also constraint in this situation, however it still remains that product counts are possibly the best choice for a single measure of product innovation. Other types of innovation, intensities, etc. might be well suited to case study analysis.

7.5 Recommendations for future research and surveys

A number of recommendations for both future research and surveys can be taken from this study. As the primary focus here was on innovation, it was not within the scope of this research to undertake a full analysis of financing within the context of bioproduct firms. However, there is substantial literature on financing for other technology development sectors, and it would be useful to investigate further the innovation-financing relationship, and how bioproduct firms succeed in securing financing of different types for their activities. Based on the results of the regression analysis undertaken here, there is no simple relationship between public financing and firm activity and innovation—rather, success in obtaining financing is likely itself a function of firm characteristics, market and economic conditions, etc. Additional work in this vein would be highly useful for both firms and policy makers. Similarly, the relationship between R&D expenditures and innovation could be explored further in the bioproduct context. This would be especially useful to policy makers to determine whether research-based incentives (for instance, the SR&ED tax credit) are truly efficient or beneficial in encouraging firms to innovate. Finally, the link between innovation and regulation could

be examined further in the context of the Porter hypothesis, in order to determine the linkages between regulation and innovation, and whether the innovation undertaken to reduce environmental/regulatory costs actually results in improvements in efficiency and profits for the firm.

This work also yields some recommendations for future surveys and research methods. The Bioproducts Development Survey contained a large amount of information, which allowed for a broad analysis of the sector and firms involved. However, given that some of the important determinants of innovation have been identified, it would be beneficial to increase the scope of some of these questions. To some extent this appears to have been pursued—for instance, the intellectual property question was modified in 2006 to include the issuing IP office, among other things. One area which could use some additional questions include use of other policy measures. Currently, the only program stated explicitly is the SR&ED tax credit. It would be useful to expand this section to include other major federal and provincial programs, especially as they continue to emerge. These changes do, however, make it difficult to include the same variables across survey years without consistency in the questions. This will particularly become an issue once additional years of surveying have been completed. In order to conduct analysis accross survey years, it will be important to have consistency in the survey questions, which will become easier once the survey has been conducted a number of times. In the meantime, there is sufficient information to complete a thorough qualitative analysis of the industry and how it is changing.

7.6 Conclusion

This research highlights the dynamic nature of the Canadian bioproducts sector. The sector has substantial potential to benefit firms, consumers, and society, and growth in the number of products, firms, and revenues per employee in Canada are encouraging. Firm strategies and characteristics such as engaging in collaborations, owning and licensing intellectual property, being focused on and dedicated to bioproduct activities, and accessing external knowledge and resources support innovative activity and help increase the product portfolio. This study points to a need for additional investigation into the financing relationship, additional types and measures of innovation, and the impact of different forms of policy on firm innovation, but also provides a solid foundation for this future research.

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Appendix 1 Regression variables & transformations from survey variables

Variable	Regression variable(s)	Survey variables/ transformations
Internal		
IP	IP dummy	IP=1 if one of 19021[5], 19031, 19041, 19051 (existing patents)>0
Firm size	SmallFirm dummy	Smallfirm=1 if Size=1
	LargeFirm dummy	Largefirm=1 if Size=3
Experience	Years in BP (YRS)	Yrs_in_BP= 2006-8020
R&D	BP R&D spending/BP employees (BPRD)	BPRD=b16062/b14082 (in 2003: b18052/TotalBPEmp)
Strategic focus	EarlyFocus	EarlyFocus=1 if no products were on the market
	LateFocus	LateFocus=1 if no products were in development
Relative importance of bps	BP_Importance	2006, BP_Importance= b16022/b16012
	(BP rev/total rev)	2003, BP_Importance= b18022/b18012
Strategic fit & resource challenges	Product/sales benefits	Multi-item scales for two benefits factors, two barrier factors, and two strategic factors from principal component analysis
	Cost/environmental benefits	
	Technology commercialization barriers	
	Bioproduct-specific barriers	

[5] Note: Codes refer to numbering for survey questions.

	Accessing external knowledge & markets Developing internal knowledge & resources	
Organizational structure	PrivateFirm	PrivateFirm=1 if b13010=1
External		
SR&ED	SR&ED Dummy (SRED)	SRED=1 if b24010=1
Collaborations	Number of collaborations (TotalCollab)	2006: b18011; 2003: b20001
Accessing financial capital	TargetMet dummy	Firms that raised 100% of the amount sought
	TargetNotMet dummy	Firms that raised <100%
Market		
Competitive environment & nature of market	Subsector: biofuels (Biofuel) Biochemicals (Biochem) Biofibre (Biofib) Other (Bioother)	Firms coded by *primary* development; for 2006 (based on highest % activity in each area) b01004..01094 coded into dummies. In 2003, used number of products[6]
Regional effects	Regional dummies: Quebec, Atlantic, Prairies, Alberta, BC	Dummies coded for each area, directly from region variable

[6] If tied and NAICS code did not clearly indicate which was the primary subsector, used more "intensive" subsector: 1st biofuels, 2nd biochem, 3rd bio other (There were very few instances which required this comparison).