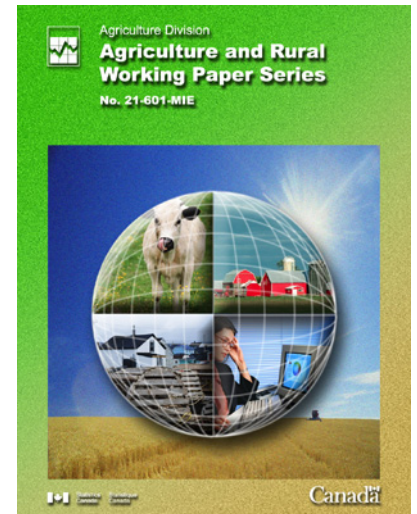**Research Paper**

Factors Affecting Biotechnology Innovation in Canada: Analysis of the 2001 Biotechnology Use and Development Survey

by Daryl van Moorsel, J.A.L. Cranfield and David Sparling

Agriculture Division
Jean Talon Building, 12th floor, Ottawa, K1A 0T6

Telephone: 1 800-465-1991

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Abstract

Advancement in biotechnology requires continued innovative activity by firms. To grow, biotechnology firms must understand the factors affecting their innovative activity. Such understanding also informs policy makers, and supports the development of policies promoting one's biotechnology sector. This study explores factors which determine innovative activity within the Canadian biotechnology industry. Innovative activity is measured as the natural log of the number of products/processes a firm has at different stages of the innovation spectrum. A model is developed to regress this measure on several determinants of innovation. Significant drivers of innovation include: collaborative arrangements, transfer of intellectual property, firm size and age, whether the firm was in the agricultural or human health biotechnology sectors and whether the firm focused on development or commercialization. Generally speaking, these factors all contributed to firms having more products/processes either under development, undergoing clinical trials or regulatory approval, or on the market.

Keywords: innovation, biotechnology, Canada, agriculture, food, human health

Introduction

Canada's highly educated population, proximity to the U.S. and relative costs of conducting research and development have created an environment conducive to the development of the business of biotechnology. Growth has been rapid, with the number of firms increasing from 282 firms in 1997 to 375 in 2001 and 490 in 2003. Canada ranks second in the number of biotechnology firms in the world, trailing only the United States (Ernst and Young, 2002). While the number of firms generating biotechnology revenues has risen from 232 in 1999 to 252 in 2001, the percentage of firms with revenue has actually decreased (McNiven et al., 2003). The Global Competitiveness Report indicates Canada slipped to fifteenth out of one hundred economies in the most recent competitive index, after being ranking sixth in the 1998 index (World Economic Forum, 2005). Clearly, Canada's future competitiveness in biotechnology depends on the policies and infrastructure in presently place to gain momentum.

Agricultural biotechnology offers unique challenges. Although Canada is a global leader in biotechnology acceptance, there is still strong resistance from many organizations regarding the adoption of agbiotech innovations. The benefits of increased crop yields and lower pesticide, herbicide, etc. usage (Associated Press, 2005) has not overcome the fears associated with the relatively new science. The persistence of consumer acceptance issues implies an uncertain future demand for agricultural biotechnology products and processes.

Changes in the biotechnology industry and broader social and economic issues underscore the need to understand the structure and characteristics of biotechnology firms and the impact of firm characteristics, strategies and environmental factors on innovative capacity and results. The purpose of this study is to evaluate possible determinants of innovation and their effect on innovative activity for agricultural and other biotechnology firms in Canada. This purpose is accomplished via econometric modelling of data from Statistics Canada's 2001 Biotechnology Use and Development Survey (BUDS). This survey provides cross-sectional, firm level data for the population of biotechnology firms in Canada in 2001.

Understanding the innovation process, and determinants of innovative activity, for Canadian agricultural biotechnology firms permits an accurate evaluation of this industry, policies that affect it and policies that can shape it. Biotechnology research in Canada is still in its infancy, and the development of this specific literature will provide further evidence of the future and direction for innovative activity in Canadian agricultural biotechnology. While focused on one country, such analysis is useful as it portrays the drivers of innovation in a dynamic and growing sector. Moreover, the analysis will enable benchmark comparisons not just overtime within Canada, but across other countries, thus enabling a systematic understanding of the pan-global drivers of innovation. The next section provides a conceptualization of the biotechnology innovation process, followed by the drives of innovation. The empirical model, data and results are then discussed, followed by a summary and conclusion.

Understanding the innovation process

The public sector has traditionally performed much of the basic research necessary to generate new biotechnology products and processes. Although public organizations (i.e. universities, hospitals, etc.) now have opportunities to further develop products/processes, private organizations are better equipped for this purpose. A firm can either generate its own ideas or use basic research developed elsewhere and apply their competencies whether they are in applied R&D, trials, regulatory issues, or production and marketing to commercialize new biotechnologies.

Sparling and Vitale (2003) developed a visual schematic to help conceptualize the development and commercialization process. Figure 1 (Sparling and Vitale, 2003) represents the four stage process of development from basic research through to commercialisation for a biotechnology firm. Before a firm becomes involved in the development process, there can often be several years of development at the basic research level. The output at this level is often the disclosure of intellectual property through patents or published papers. An idea does not need to be disclosed but has a much greater chance of attracting financing if it has been peer reviewed and accepted as novel and useful idea beyond that of the researcher (Deeds and Hill, 1996, Niosi, 2000).

Once a product has passed the idea generation stage, it will enter the first of four stages of development undertaken by firms. The first stage is firm level R&D, which prepares a product/process to enter the second stage of clinical or field trials. If a firm lacks the competency to perform R&D or field/clinical trials they can contract out these activities or form a collaborative arrangement to procure these services. This is also an opportunity for firms proficient in R&D and trials to generate revenue by performing these services for other firms.

For agbiotech firms, stage two requires a product/process to pass safety requirements while proving its effectiveness. The clinical testing required for the human health sector is a much more stringent evaluation, where clinical trials occur in three successive phases to provide the greatest amount of protection possible for probable users of the product/process. Stage two would be equivalent to the firm completing phase one trials proving the safety of the product and entering phase 2.

Firm level R&D and field/clinical trials are often performed by small and medium sized enterprises (SMEs) also referred to as dedicated biotechnology firms (DBFs). This process typically takes from 2-5 years and produces different possible outcomes. An SME can either try to continue developing the product/process after these two initial stages or sell or license their work to a large multinational firm proficient in the later development stages.

Stage three in the process of biotechnology product/process development is the regulatory phase/unconfined release assessment phase. This costly and lengthy stage is seen as a barrier to many SMEs (Blind, 2004; Industry Canada, 2000) and is where many technologies are sold or licensed to large multinational firms with the resources

needed to complete this phase. The last development stage is the market development stage where production, marketing and distribution become key factors. The obvious strengths of large firms with respect to production, marketing and distribution of products/processes lead to their dominant role in commercialisation.

The four stages of product/process development can be grouped into either an early focus (stages one and two) or late focus (stages three and four). Firms focused in the early, or research focused, stages will have products/processes only in stages one and two of development. In contrast, firms focused on late stages of development have no early stage products/processes.

Drivers of innovation

The purpose of this study is to understand what factors influence innovation within Canada's biotechnology industry. This section will review the factors which have been found to shape the innovation in various sectors and countries, with an eye to developing covariates for an empirical model.

Collaborative arrangements

Collaborative arrangements (CA's) allow firms to focus their activities in specific areas to where they have a competitive advantage and access needed technologies and capabilities not present within the firm. Mohnen and Therrien (2003) suggest there is a positive relationship between any collaboration and innovative sales share controlling for firm size, sector, R&D status and government subsidies.

For inter-firm relationships, CA's are important to counteract the lack of integration for biotechnology firms. The biotechnology industry is characterised by a large number of small start-up firms without the capacity to take a product/process from initial R&D through to commercialisation. Baum et al. (2000) found that managers of start-up biotechnology firms gain advantages from alliances at start-up and that they should continue to develop alliances while establishing themselves, as the need for alliances does not decrease over time.

Large corporations use CA's to supplement their own internal development capabilities, taking advantage of their competencies in legal and regulatory issues, and marketing, production and distribution. A positive relationship is expected between innovative activity and the number of collaborative arrangements in which a firm participates.

Capital requirements

With approximately 20% of Canadian biotechnology firms generating profits or at least breaking even (Ernst and Young, 2003) financing is a crucial factor for firm survival. Financing for biotechnology firms can come from a number of different investment sources. Most commonly, venture capital whether it be Canadian or American, is

sought to finance operations but firms also seek capital from angel investors, government programs and initial public offerings, More traditional forms of financing such as banks and family resources are also available.

Raising capital can often times be a difficult task depending on the investment climate. The stock market crash in 1987 was the first difficult investment time period for biotechnology firms. In early 1992, with a number of American drugs failing clinical testing, the investment climate for biotechnology firms once again spiralled downward (Niosi, 1995, pp.81). Most recently, the technology boom and bust of the late 1990's and early 2000's is another good example of the instability of financial markets facing biotechnology firms. Revenue generation has now become essential for all biotechnology firms as external financing in 2002 dropped to 40 percent and 45 percent of funding levels in 2001 and 2000, respectively (Ernst and Young, 2003).

Raising capital is not only difficult in weak investment climates; even in good economic times capital rationing takes place where capital suppliers, even for promising technologies, hold back their capital to reduce their risk. Early stage technologies increase the dangers of asymmetric contracts reducing the willingness of lenders to finance innovative projects. A positive relationship is expected between innovative activity and the level of available capital.

Research and development effort

Research and development is often cited as a key input for the growth of innovative activity within a firm. Investing in R&D enables a firm to have focused physical research resources and available scientists for the development of new products and processes. R&D effort is important for the creation of world class innovations (Cozzarin, 2003) but is neither a necessary nor a sufficient condition for innovation (Baldwin, 1997; Akerblom, Viraharju and Leppaahti, 1996).

Questions have been raised with regard to the accurate measurement of all R&D, portions of R&D that cannot be measured and appropriability concerns for R&D. For example, R&D budgets underestimate the innovative activity of small and medium sized firms as they do not have the same formal R&D budgets as large firms and must rely on technology adoption or other firm's innovative capacity (Tourigny and Le, 2003). SME's have also been suggested to undertake less R&D than large firms because expected returns of R&D increases with firm size (Nooteboom, 1991). Finally, the propensity to invest in R&D is determined by the appropriation of R&D benefits by the firm. The firm that undertakes R&D and is successful is not guaranteed the compensation for an innovation. For example, the inability of firms to achieve perfect price discrimination may be another factor affecting a firm's ability to recoup their large R&D expenses (Harabi, 2001). These suggested differences in the structural characteristics suggest the need to explore the relationship between R&D effort and innovative activity further. Consequently R&D effort variables consisting of firm R&D spending and personnel will be included as explanatory variables in the regression.

Firm size

A key component of the innovation literature is devoted to the effect of firm size on innovative activity. Cohen and Klepper (1996) suggest that large firms have an advantage in undertaking R&D and also realise greater returns from R&D. Cost-spreading is the prominent reason for size advantages of undertaking R&D while a greater return from R&D has a deeper explanation. Larger firms, active in R&D, will produce less overlapping research than a number of small firms unaware of the R&D a competitor is undertaking. Consequently, for an industry or sector, less overlap in R&D effort will result in a greater realisation of R&D effort.[1]

While firm size is suggested to have a positive effect on R&D effort, it may not have the same relationship with other measures of innovation activity. Cohen and Klepper (1996) conclude that the number of innovations per dollar of R&D actually declines with firm size. This could be due to the fact that larger firms tend to take products though the very expensive last stages of commercialisation. More recently, Traore (2004a) found that the cost spreading advantages of large biotechnology firms (those with more than 150 employees) was offset by the flexibility of small or medium sized firms. Given the conceptual uncertainties with respect to firm size and innovative activity, firm size covariates must also be developed and included.

Intellectual property transfers and contracting

Intellectual property transfers create opportunities for networks to share resources whether through the sale of patents, licensing agreements or material user agreements. For firms focused at the later stages of product/process development, acquiring IP is an excellent strategy to augment their pipeline while still focusing on their core competencies. Conversely, some firms grant IP rights to generate revenue by selling or licensing IP, or to get some benefit from non-core discoveries. Some firms focus solely on development work with the goal of granting or selling their IP rather than seeing a project through to a commercial product.

Contracts and collaborations can speed up product development by providing capabilities not present in the firms enabling firms to develop their principal innovation faster. Regardless of whether a firm is focus on IP granting, acquiring or contracting, it stands to reason that the number of products/process is positively related with these activities.

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1. Cohen and Klepper's synthesis of firm size effects is partially based on Schumpeter's 1942 seminal work. Schumpeter (1942) suggested that large firms have advantages because they have an established infrastructure in production, marketing, distribution as well as financial resources to exploit new technologies. More recent proponents of large firm advantages for innovation (Kraft, 1989; Bhattacharya and Bloch, 2004) reinforce these arguments through empirical investigations.

Patenting

Much research has focused on the relationship between patents and innovation. Patents can be viewed as an intermediate output of the innovation process. This implied relationship and the fact that patents may be measured easily are the reasons why patents have often been used as a proxy for innovation. Unfortunately, patents, similar to R&D, are neither a necessary nor sufficient condition for innovation. The protection they provide is often overstated with little empirical evidence to back it up (Cohen, 1996). Patents have been linked to rapidly growing biotechnology firms, but Niosi (2000) suggests the importance of patents is to signal venture capital investors of a novel and worthy technology.

Patents have mostly been found to be effective only for pharmaceutical industries (Scherer, 2002) with other forms of intellectual property protection found to be more effective in other sectors. Moreover, in some sectors very little patenting is used at all. Avermaete et. al (2003) suggest that innovations in small food processing firms are seldom patented. However, patents do signal some innovative capacity and therefore ought to be considered as a driver of innovation.

Sector characteristics

Biotechnology products and processes span agriculture, food, human health, the environment and other industries (McNiven, 2001). Sector differences are most affected by the technological opportunities and competitive conditions of a sector. Cohen (1996) suggests, as a result of more science-friendly environments, the technological advance per unit of R&D is greater in some industries than others. Moreover, the competitive conditions of an industry also affect sub-sector differences. A sector may encounter a monopolistic or highly concentrated industry or may face fierce competition. Both types of competition, whether high or low, have been hypothesized to have positive effects on innovation. Consequently, one might expect sector specific effects to arise in any study of cross-sectoral innovative activity. As such, covariates will be developed to account for such effects.

Firm characteristics

For an emerging industry like biotechnology, two firm characteristics are often discussed, firm age and whether or not the firm is a public or privately held company. Age, which suggests experience, has been positively linked to the creative or innovative capacity of a firm (Traore, 2004a). Age has also been suggested to partly explain the rapid growth of Canadian biotechnology firms (Niosi, 2000).

A major difference between publicly traded firms and privately held firms is the priorities of stakeholders. For publicly traded firms, the firm is ultimately responsible to the shareholders and must prioritize their activities in such a way. On the other hand, privately held firms can decide on their priorities internally. Public companies also

tend to have greater assets at their disposal. Although both types of firms have advantages, their effect on the innovative activity of a firm is uncertain.

Strategic focus

Firms can focus their efforts on either early stage development, late stage commercialization or be comprehensive in the scope of their innovative activities. While the literature is somewhat silent with respect to the role these different foci might play, it is nonetheless important to account for such firm level perspectives as these will speak not only to the firm's core competencies, but also capture conscious strategic decisions a firm makes and concomitant ability to manage the innovation process.

In summary, the innovative ability of firms can be driven by factors including engagement in collaborative arrangements, capital requirements and access, R&D effort, firm size, intellectual property transfers and contracting, patenting, firm and sector characteristics and the strategic focus of the firm. This paper examines whether these factors affect the innovative capacity of Canadian biotechnology firms and the nature of the impact.

Empirical model

To determine the influence of various factors on innovation in the Canadian biotechnology industry, one must first be able to measure innovation. The two most common measures include research and development activity (Hamberg, 1964, Scherer, 1991) and patent registration statistics (Griliches, 1990, Scherer, 1965). Recent Canadian research has focused on measuring innovation by classifying a firm as either an innovator or not (Baldwin and Sabourin, 1999) or by the number of products/process in development (Traore and Rose, 2003; Traore, 2004a).

Two important factors in selecting the innovation measurement indicator for this study include: 1) the availability of data and 2) distinct industry characteristics. Although R&D expenditures and patent statistics have a rich history, their weaknesses have been routinely pointed out throughout the innovation literature (see, for example, Brouwer and Kleinknecht, 1997; Kleinknecht, Brouwer and Van Montfort 2002). The biggest flaw of these innovation measurement indicators is their inability to link the measures with a final outcome (i.e., a commercialised product or process). Moreover, defining innovation as a process that results in a new or significantly improved product or process (OECD, 1992) suggests the importance of measuring innovation at the furthest commercialization stage possible. This means accounting for both pre-market and on the market products/processes when trying to measure innovation.

Accounting for products/processes in pre-market development stages is important for industries, such as biotechnology, that lack integration. As previously discussed, a firm that cannot operate at later stages of development will be forced to develop products only to a certain stage and sell off or license their technology before being able to

commercialize it. Focusing only on market products ignores the early stage niche firms who would never have products on the market. However, these firms are important sources of ideas and products for larger integrated and late stage firms. The inclusion of products/processes across all stages of development will allow an innovation measurement indicator to account for innovative firms who are focused in early product/process development stages.

Taking into account the availability of data and specific characteristics of the Canadian biotechnology industry, the most suitable indicator of innovative activity is the total number of products/processes across all stages of development for a firm.[2] This approach was followed by Traore (2004a). We build on his work by expanding the modeling strategy beyond the total number of products at all stages of the innovation spectrum (i.e. pre-market and on the market), and also model the number of products for the early focused firms and late focused firms. Such analysis allows one to determine whether different drivers of innovation have a differential effect across the innovation spectrum.

The relationship between the number of products/processes a firm has (either in total or in the early or late stage of the innovation process) and measures related to the drivers of innovation is captured using equation (1). Here, the natural log of the number of products is regressed on covariates related directly to the drivers of innovation:

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2. A caveat to using this measure of innovation is that it does not account for the value of an innovation. There have been numerous attempts to devise a value scheme for innovations using terms such as "radical" or "incremental" or "discontinuous", but no consensus has been reached (Garcia and Calantone, 2002). The concept adopted by Statistics Canada and used in their 1999 Survey of Innovation defines an innovation as a world-first, Canada-first or firm-first but this rating has not been included in the BUDS surveys. Attaining a measure of innovation values would be very important as a weight could be attached to each product/process. Accepting this limitation and the need for developing a consistent and singular value scheme for innovations is an extension of all present innovation research.

$$\ln(N_i) = \beta_0 + \beta_1 Burnrate_i + \beta_2 RDemp_i + \beta_3 OtherEmp_i + \beta_4 ExPatent_i$$

$$+ \beta_5 CapitalRaised_i + \beta_6 IPgrant_i + \beta_7 IPacq_i + \beta_8 TotCol_i$$

$$+ \beta_9 RDcontracts_i + \beta_{10} Regcontracts_i + \beta_{11} Early_i + \beta_{12} Late_i \qquad (1)$$

$$+ \beta_{13} Firmage_i + \beta_{14} PriPub_i + \beta_{15} Size1_i + \beta_{16} Size2_i + \beta_{17} Agbio_i$$

$$+ \beta_{18} Foodpro_i + \beta_{19} HuHeal_i + \varepsilon_i.$$

In equation 1, $\ln(N_i)$ is the natural log of the number of products/processes for the ith firm. The capital burn rate of the firm, $Burnrate_i$, defined as the ratio of biotechnology revenue to biotechnology R&D expenditure, is related to the capital requirements driver, and is hypothesized to have a positive effect.

The ratio of biotechnology R&D employees to the total number of employees, $RDemp_i$, has been included as a relative measure of R&E intensity within the firm, while the ratio of non-R&D biotechnology employees to total number of employees, $OtheEmp_i$, has also been included to capture their role in supporting R&D. Specifically, non-R&D employees serve an important R&D supporting role, such as financial, marketing, managerial, production, etc. for biotechnology products/processes, and could work to improve R&D effectiveness and increase the innovative capacity of the firm. Both $RDemp_i$ and $OtheEmp_i$ are hypothesized to have positive effects.

The existing number of patents, $ExPatent_i$, naturally captures the role of patents as a driver of innovation and is expected to have a positive sign. An additional capital based drive, $CapitalRaised_i$, measures the dollar value of capital raised by the firm for biotechnology related purposes and is also expected to have a positive effect. The role of intellectual property transfers is captured via $IPgrant_i$ and $IPacq_i$, which account for whether a firm grants or acquires IP, respectively. $IPgrant_i$ ($IPacq_i$) is a dummy variable assuming a value of one of the firm grants (acquires) IP. Both of these dummy variables are expected to have a positive sign, in keeping with the role of IP transfers. The total number of collaborative arrangements is expected to also be positive and captured via $TolCol_i$. The effect of R&D and regulator/clinical contracting, which is related to IP transfer and contracting, is accounted for $RDcontracts_i$ and $Regcontracts_i$, respectively, which measure the dollar value of these activities. As with the IP variables, these are expected to have a positive effect on innovative activity.

Two dummy variables, $Early_i$ and $Late_i$, are used to reflect the strategic focus of the firm. $Early_i$ equals one if a firm only has products in the first two stages of the

innovation process, and zero otherwise, while $Late_i$ assumes a value of one if the firm only has products/processes in the last two stages and zero otherwise. The early and late focus variables are compared to comprehensive firms, which are defined as firms without an early of late focus. The relationship between early, late and comprehensively focused firms and their effect on the innovative activity of a firm is uncertain.

Other firm specific variables include $FirmAge_i$, which measures the age of the firm, in years, in 2001, and $PriPub_i$, a dummy variable assuming a value of one if the firm is publicly owned. Firm age is expected to have a positive relationship with innovative active (as age generally carries with it a connotation of experience which might make innovation easier), while the nature of firm ownership is expected to have an uncertain effects. Firm size dummy variables representing small ($Size1_i$) and medium ($Size2_i$) sized firms are included. $Size1_i$ equals one if the firm has less than fifty employees and zero otherwise; $Size2_i$ equals one if the firm has between 50 and 150 employees and zero otherwise. Large firms, which will be used as the reference sector, will be firms with more than 149 employees. Based on the inconsistent and contradictory results of previous empirical attempts, firm size effects are uncertain.

Lastly, sector specific dummy variables are included to narrow the focus on the agricultural, food processing and human health biotechnology sectors. $Agbio_i$ ($FoodPro_i$, $HuHeal_i$, respectively) equals one if the firm has the majority of products in the agricultural (food processing, human health, respectively) biotechnology area and zero otherwise. The reference or "other" sector consists of firms in the natural resource, environment, aquaculture and bioinformatics sectors. The hypothesized relationship of the agbiotech and human health coefficients is positive based on the high-tech nature of these industries. Conversely, the food processing sector is hypothesized to have a negative relationship based on its low-tech nature.

Data and estimation

Data for this study are taken from Statistics Canada's 2001 Biotechnology Use and Development Survey (BUDS). A screening process was used to identify firms involved in biotechnology development. A one page questionnaire was sent to 11,262 firms and had a 70 percent response rate. If a responding firm reported using or developing biotechnology products and processes, they were sent a second stage survey. The latter survey was sent to 900 firms, with 646 questionnaires being returned. In the end, 253 firms indicated involvement in developing biotechnology products and processes and accounting for non-responses, the population is estimated to be 375 (Traore, 2004b).

The questions asked in the second stage survey span topics ranging from the specific biotechnologies a firm used, to the number of products/processes they have in

development, to more traditional firm characteristics such as firm age and business strategies, as well as sector which the firm belongs.[3] A list-based definition of biotechnology was also included to allow firms to identify where they belonged in nineteen biotechnology categories.[4] Table 1 provides summary statistics for the dependent and independent variables.

For this empirical analysis, the assumptions of the classical linear regression model were assumed and the models were estimated using OLS on standardized data in Statistical Package for the Social Sciences (SPSS).[5] Namely, the regression model was linear in the coefficients, had an additive error term and was correctly specified. Moreover, the error term was normally distributed with mean zero ($E[\varepsilon] = 0$); a constant variance ($Var[\varepsilon] = 0$); and uncorrelated error term observations ($Cov[\varepsilon_i, \varepsilon_j] = 0$ for all i,j). While omitting interaction terms is a weakness of the model, it was choice taken to preserve degrees of freedom.

Empirical results

Four different models were estimated. The difference lies in the sub-set of firms used for estimation. In the first case, all firms were included in the regression model (and so it is referred to as the general model). The data were then parsed into three mutually exclusive sets of firms, delineated on whether the firms was an early focus, late focused or comprehensively focused firm. The model was subsequently applied to these three foci based sub-sets, with removal of the strategic focus variables.

Results for the general model are reported in Table 2. White's (1980) test for heteroskedasticity indicates rejection of the null hypothesis of heteroskedastic errors at the five percent level. As well, the joint null hypothesis of zero slope coefficients was also rejected at the one percent level, while the adjusted R^2 was 0.353. In terms of significant covariates, the intercept (which has a value of zero in the standardized regression model) is significant at the one percent level. So too is coefficient medium-sized firm dummy variable (Size2). This suggests that medium-sized firms (50-150 employees) have greater innovative activity compared to large firms. The firm size debate focuses on the entrepreneurial nature of small firms stifled by a lack of resources versus the bureaucratic nature of large firms. Medium-sized firms can still maintain an entrepreneurial nature while having greater resources than small firms but less

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3. The survey classifies firms into seven sectors: agriculture, food processing, human health, natural resources, environment, aquaculture and bioinformatics.
4. 19 biotechnology categories separated into 5 major blocks. There is an additional "other" category that includes bioinformatics and nanobiotechnologies and space to provide any unlisted biotechnologies.
5. Some may question the use of OLS to estimate the specified model. In theory, accounting for the count data nature of the data should be required. Note, however, that following Traore (2004), we have also undertaken a non-linear transformation which changes these integer values into real numbers. Moreover, no observations have zero counts in any of the models, while the data are standardized by subtracting their mean and dividing by their standard deviation. As such, any potential impact of using OLS should be minimized.

bureaucracy than large firms. They also may not be focused on the very expensive final stages of commercialization. In today's global economy, medium-sized firms can attain international goals but they can also fill niche markets for Canadian consumers.

The number of collaborative arrangements a firm has in place (# of Collaborative Arrangements) is also significant at the one percent level, and positive indicating a positive link between the number of collaborative arrangements a firm has in place and the innovative activity for a firm.

Significant and positive coefficients were estimated for the intellectual property rights granted and acquired dummy variables (# of IP rights granted and # of IP rights acquired). IP acquisition has a similar effect as CA's - it increases internal knowledge through external sources. By acquiring IP a firm can increase the number of products under development. By granting IP a firm may increase it's credibility thereby increasing its probability of securing new resources. If the IP is granted through a licensing arrangement, the revenue from the license can increase a firm's resources available for innovations.

Amongst the sector dummy variables, only that for agbiotech (Agbiotech dummy) was significant, and is positive. The food processing (Food Processing dummy) and human health (Human Health dummy) dummy variables, which had 48 and 197 firms, respectively, were just outside the ten percent level of significance and also had positive coefficients. So, relative to the "other" sector, the agricultural biotechnology sector had greater innovative activity. This result seems a natural outcome given that agbiotech firms, specifically plant biotechnology, produce a large number of products/processes or varieties with very small differences.

The last significant results for the general model involve the strategic focus dummy variables. The early and late focus (Early Focus dummy and Late Focus dummy) dummy variables are significant at the one percent level, but negative. Relative to comprehensively focused firms, firms whose strategic focus is on the either the early or late stages of develop have fewer products. Although these results suggest the importance of comprehensively focused firms, this strategy may not be feasible for firms with limited capacities. Moreover, policy and market changes may be necessary to remove the barriers that prevent a firm from developing products at a certain stage.

The significance of the early and late focus dummy variables underscores the analysis of the sub-sets of firms who are in these two groups, and the firms in the comprehensive group. Equation 1 was estimated with using data from these three sub-sets, but excluding the early and late focus dummy variables. Results for these three models are also shown in Table 2, under the headings Early Focus, Comprehensive Focus and Late Focus. For information, note that early, late and comprehensively focused firms account for 168, 47 and 160 firms, respectively.

The adjusted R^2 for these models ranges from 0.085 (for the late focused set of firms) to 0.387 (for the comprehensively focused firms). Except for the late focused firms, the joint null hypothesis that the estimated slope coefficients equal zero is rejected at the

one percent level. However, this null could not be rejected for the late focus regression, a result which likely reflects limited degrees of freedom in this regression. Because of limited degrees of freedom on the sub-samples of data, White's heteroskedasticity test was not conducted.

While the number of significant coefficients in each of the three foci model, the results do suggest some interesting observations. For the early focused model, the IP acquisition and firm age coefficients were significant (and positive) at the one percent level, while human health coefficient was significant (and positive) at the ten percent level. Results for the firm age variable suggests older firms in the, early focus group, are better able to engage in innovative activity, which may reflect the notion that older firms have had more time to adequately find their niche in the segregated biotech industry. The sign on the human health dummy variable (which suggests firms in this sector have more products than the other category) is not surprising. Early focused, health oriented firms often have a large number of products under development. Such scale of development reflects the fact that within the health sector, it takes many attempts to identify a single successful drug.

The second strategically focused model based on the 2001 BUDS is the comprehensively focused model. These 168 firms exhibit the type of business model that incorporates all aspects of product/process development. Results from the general model suggested that comprehensively focused firms have a greater innovative activity based on the number of products/processes they have in development. The coefficients for the medium-sized firm variable, IP rights granted, IP rights acquired and agricultural biotechnology variables are significant at the one percent level and positive, while the firm age variables is also positive and significant at the five percent level. As with the early focused regression these results underscore the importance of experience in shaping innovation activity.

In the late focused model, the number of collaborative arrangements variable had a significant (at the one percent level) and positive coefficient, while that for the human health dummy variable was negative and significant (at the five percent level). The first result underscores the importance of collaborations as a means of bring products into the pipeline of late focus firms. The human health variable result is not surprising since firms can afford to shepherd only a few products through the very expensive final stages of commercialisation.

Summary and conclusions

This study sought to understand what factors determine innovative activity within the Canadian biotechnology industry. This was accomplished by developing a model where the natural log of the number of products/processes a firm has at different stages of the innovation spectrum was regressed on determinants of innovation. The latter included variables capturing R&D capacity, access to outside knowledge, capital

requirements and usage, firm and sector characteristics and the strategic focus of the firm.

In broad terms, results underscore the importance of collaborative arrangements, transfer of intellectual property, firm size and age, whether the firm was in the agricultural or human health biotechnology sectors. Generally speaking, these factors all contributed to firms having more products/processes either under development, undergoing clinical trials or regulatory approval, or on the market. The focus of a firm on either early (development) or late (commercialisation) stages of innovation exclusively had a negative effect on the number of products. Firms which undertake all innovation activities tended to have more products than firms which focused on development only or regulatory/commercialization only.

This study's findings represent a contribution to innovation research literature, and to the emerging biotechnology industry in Canada. As the Canadian biotechnology industry evolves, the need to understand factors affecting innovative activity and the development of new products and processes will continue from both a firm and policy perspective. The shifting focus of agriculture in Canada from production to bio-economy initiatives will require continued theoretical and applied research in this area.

Acknowledging some of the consistent results of this study present a focused opportunity for policy makers. Increasing the ability of firms to form alliances, either formally or through IP sharing, will strengthen the ability of firms to generate new products/processes. As well, adjustments to policy that can benefit small and medium sized firms and the creation of these firms will benefit the Canadian biotechnology industry. Another initiative for policy makers will be to promote policy that will allow firms to take products/processes through the entire value chain, if they desire. This study's results showing greater innovative activity for comprehensively focused firms suggests that policy should be structured to enable firms to take products through all stages of development. Enabling firms to extend their product development will greatly benefit the industry while not pressuring firms to shift their focus. For early focused firms that are satisfied with their present focus, they can still stay focused on early stage development and in the market of idea generation.

The implications of this study should not be left only to policy makers. Biotechnology managers should be actively seeking out new ways to increase their operations. Managers can definitely benefit from effectively seeking out collaborative arrangements, granting and acquiring IP and improving internal competencies to develop products and processes at more stages along the development cycle. As firms face constant decisions whether to increase stocks of knowledge through collaborative arrangements, IP transfers or vertical integration, managers should be aware of both the positives and negatives associated with searching out any type of cooperative strategy. If properly arranged, biotechnology managers can benefit in many different ways through networks of collaboration.

The results of this study provide evidence supporting determinants of innovative activity for biotechnology firms in Canada. As this study examines 2001, results should be carefully interpreted and may be subject to change when studied over time. The biotechnology industry is important to Canada for many reasons. The transformation of Canadian society towards a knowledge-based economy is an opportunity for knowledge intensive industries, like biotechnology, to flourish. For Canadians, developing leading edge facilities and technologies will allow us to continue our high standard of living while also trying to have input in global social issues. Biotechnology has proven to produce life saving technologies, and Canadians should embrace these prospects to extend our role in these initiatives. The growth of the biotechnology industry, and enlightening statistical analysis of the biotechnology industry will continually add insight and opportunity for all parties involved.

Successful in meeting its objectives, this study addresses a long studied and ongoing facet of economic research. This study has contributed significantly to the understanding of innovation in the industry by looking at innovation through different measures and assessing how different factors affect innovation. Innovation research will continue to grow as both the supply and demand of new products and processes carries on.

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Figure 1 – Biotechnology Commercialization: Process and Roles
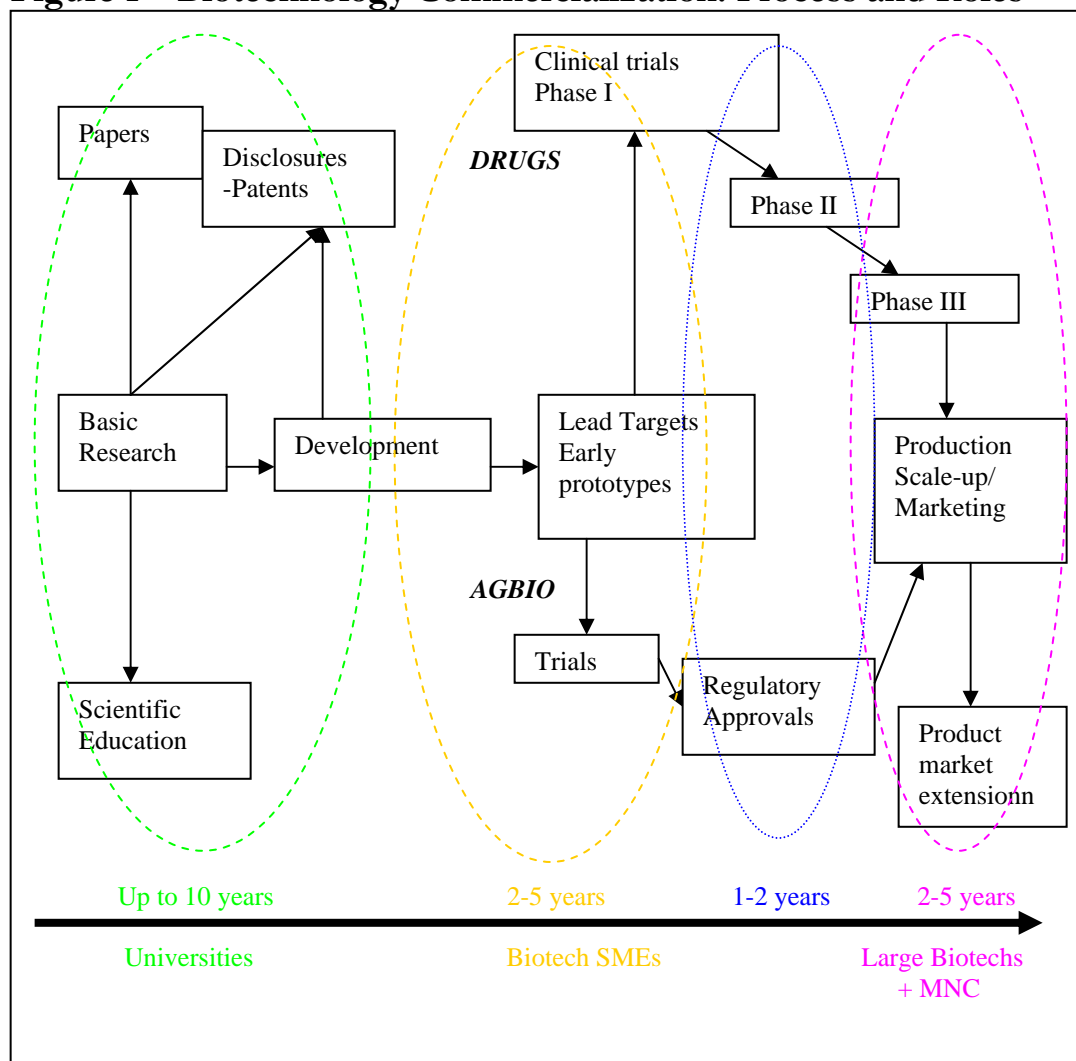
Source: Sparling and Vitale, 2003. *Australian Biotechnology: Do Perceptions and Reality Meet?,* Report to the Australian Stock Exchange on biotechnology IPOs 1998-2002, 2003.

Table 1 –Descriptive Statistics[a]

	All firms	Early Focus	Comprehensive Focus	Late Focus
Log of Number of Products	1.88	1.36	2.55	1.44
	1.36	1.02	1.38	1.34
Size1 (< 50 employees)	0.71	0.84	0.64	0.55
	0.45	0.37	0.48	0.5
Size2 (50-150 employees)	0.16	0.11	0.13	0.32
	0.36	0.31	0.36	0.47
R&D biotech employees/employees	0.46	0.57	0.39	0.28
	0.31	0.28	0.27	0.32
Non-R&D biotech employees/employees	0.27	0.24	0.31	0.28
	0.27	0.23	0.27	0.31
R&D contracting ($000s)	552.27	524.89	632.66	375.01
	2056.44	2063.45	2103.42	1889.17
Regulatory contracting ($000s)	325.9	125.02	238.31	1351.77
	2938.21	781.09	1459.15	7737.01
# of Collaborative Arrangements	3.06	2.9	3.49	2.17
	6.82	7.56	6.58	4.24
# of IP rights granted	4.36	0.21	9.97	0.09
	66.78	0.94	102.11	0.38
# of IP rights acquired	1.06	0.44	1.92	0.37
	5.51	2.03	8.1	0.82
# of existing patents	12.42	4.17	16.18	29.26
	68.95	11.19	77.64	129.99
Burnrate	43.38	5.84	83.97	39.5
	454.2	26.48	689.93	132.58
Private firm/Public firm dummy	0.25	0.19	0.33	0.19
	0.43	0.39	0.47	0.4
Firm age	13.41	8.22	16.28	22.26
	19.59	12.48	21.79	26.64
Capital Raised ($000s)	2352.51	2889.7	2412.15	208.65
	7398.87	8382.04	7280.18	742.85
Agbiotech dummy	0.17	0.12	0.22	0.23
	0.38	0.32	0.41	0.42
Food Processing dummy	0.13	0.04	0.2	0.2
	0.34	0.2	0.39	0.4
Human Health dummy	0.52	0.67	0.46	0.22
	0.5	0.47	0.5	0.41
Early Focus dummy	0.45	…	…	…
	0.49	…	…	…
Late Focus dummy	0.12	…	…	…
	0.33	…	…	…

a. Mean value shown above, standard deviation shown in parentheses.
…   not applicable

Table 2 – General and Strategic Foci Model Regression Results

	All firms		Early Focus		Comprehensive Focus		Late Focus	
	Estimate	t-Statistic	Estimate	t-Statistic	Estimate	t-Statistic	Estimate	t-Statistic
Constant	…	**6.056***	…	**1.766***	…	**3.159***	…	1.604
Size1 (< 50 employees)	-0.075	-0.928	-0.176	-1.048	-0.012	-0.111	-0.154	-0.351
Size2 (50-150 employees)	0.147	**2.160***	0.092	0.623	0.293	**3.032***	-0.282	-0.753
R&D biotech employees/employees	0.018	0.315	0.145	1.467	-0.012	-0.133	-0.094	-0.445
Non-R&D biotech employees/employees	-0.01	-0.188	0.019	0.209	0.073	0.925	0.09	0.365
R&D contracting ($000s)	0.035	0.72	0.008	0.107	0.033	0.433	-3.517	-1.037
Regulatory contracting ($000s)	-0.06	-1.383	-0.036	-0.469	0.002	0.017	-0.447	-0.896
# of Collaborative Arrangements	0.1	**2.221***	0.084	0.949	0.091	1.294	0.508	**2.577***
# of IP rights granted	0.263	**6.043***	0.07	0.865	0.464	**6.400***	-0.015	-0.089
# of IP rights acquired	0.169	**3.576***	0.151	**2.052****	0.21	**2.630***	0.241	1.034
# of existing patents	-0.047	-0.936	0.005	0.065	-0.083	-1.052	3.62	1.081
Burnrate	-0.03	-0.699	-0.084	-1.111	-0.078	-1.157	-0.137	-0.798
Private firm/Public firm dummy	-0.033	-0.693	-0.025	-0.301	-0.049	-0.587	-0.161	-0.652
Firm age	0.087	1.515	0.226	**2.604***	0.197	**1.994****	-0.086	-0.39
Capital Raised ($000s)	0.022	0.458	0.127	1.456	-0.146	-1.515	0.185	0.894
Agbiotech dummy	0.212	**3.871***	0.103	1.104	0.401	**4.302***	-0.043	-0.206
Food Processing dummy	0.082	1.514	0.082	0.992	0.147	1.556	-0.106	-0.53
Human Health dummy	0.097	1.52	0.179	**1.783***	0.138	1.206	-0.488	**-2.336****
Early Focus dummy	-0.341	**-6.965***	…	…	…	…	…	…
Late Focus dummy	-0.246	**-5.202***	…	…	…	…	…	…
Adj. R²	0.353	…	0.165	…	0.387	…	0.085	…
F-Test	11.478*	…	2.953*	…	6.905*	…	1.251	…
Sample Size	375	…	168	…	160	…	47	…
White's Test	117(1)	…	…	…	…	…	…	…

*,**,***, indicate a 1%,5% and 10% level of significance, respectively

1 – The critical value of χ^2 with 209 degrees of freedom is 244 at the 5% level of significance.

…   not applicable

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