Paper to be presented at the AAEA annual meeting

An Analytical and Empirical Analysis of the Private Biotech R&D Incentives

by:

Stavroula Malla[*] and Richard Gray[†]

---

[*] Stavroula Malla is a SSHRC Post-Doctoral Fellow in the Department of Agricultural Economics of the University of Saskatchewan, and a visiting scholar at the Department of Agricultural and Resource Economics of the University of California at Davis. Contact: S.Malla@usask.ca or malla@primal.ucdavis.edu .

[†] Richard Gray is a professor in the Department of Agricultural Economics of the University of Saskatchewan.

An Analytical and Empirical Analysis of the Private Biotech R&D Incentives

By

Stavroula Malla[*] and Richard Gray[†]

Abstract

The study examines the incentives and incidence of private R&D investment in the today' biotech industry. A three-stage search/imperfect competition model is developed to derive the optimal pricing and investment decisions of private firms and to develop conjectures about how these decisions are affected by exogenous factors. The analysis shows that basic public research "crowds in" applied private research while applied public research "crowds out" applied private research. The current technology level and the cost of the experimentation negatively affect private investment, while the price of the final product positively affects the private investment. Moreover, the greater the product heterogeneity, the higher the price charged with the same amount of R&D. Finally, the increase in IPR's and the firm's market size has a positive effect on the private firm's amount of R&D investment. These conjectures are tested empirically using data from the Canola research industry. The results of the empirical analysis strongly support the results derived from the theoretical model.

Key words: search processes, stochastic process, imperfect competition, differentiated products, heterogeneous farmers, biotechnology, IPRs, basic research, applied research, private incentives, canola R&D.

---

[*] Stavroula Malla is a SSHRC Post-Doctoral Fellow in the Department of Agricultural Economics of the University of Saskatchewan, and a visiting scholar at the Department of Agricultural and Resource Economics of the University of California at Davis. Contact: S.Malla@usask.ca or malla@primal.ucdavis.edu .

[†] Richard Gray is a professor in the Department of Agricultural Economics of the University of Saskatchewan.

1. Introduction

Agricultural research is an important driver of economic growth. Specifically, technology is a key determinant in economic growth at the national level (Solow 1957, Romer 1990). It was shown that the post-war growth in agriculture has exceeded the growth in other sectors (Jorgenson and Gollop 1992). Alston et al. (2000) estimate that the average reported rate of return for agricultural research and development worldwide is 73 per cent per year. Consequently, agricultural R&D investment is a very important economic issue.

Crop research has undergone a major transformation in North America and many other parts of the world. In the 1980s crop varieties were open-pollinated, non-transgenic and had no effective Plant Breeders Rights (PBR). However, in the 1990s PBR were established, the US patent office started to recognize the biotech process, and the industry often had license agreements for products. Finally, some of the technologies allowed exclusion from others from using it, such as hybrid varieties that require the purchase of the seed every year in order to keep the desirable traits, herbicide-tolerant varieties that tied to the use of particular herbicides or designer varieties meant to be processed in a specific place.

As a result of all these changes, the products of research are now effectively protected by IPR, which were made enforceable through the use of biotechnology. Biotechnology and IPR have altered the nature of the research products from non-rival and non-excludable to rival and excludable goods. This change in the nature of research products transformed most crops from a public good to excludable private goods. At the same time, the inherent non-rival nature of research products, meaning that the production function exhibits increasing returns to scale (Romer 1990), tends to create a concentrated private crop industry as firms move to capture economies of scale and scope (Fulton 1997, Fulton and Giannakas 2000). A further push toward integration occurs as firms adopt strategies to preserve their own *freedom to operate* (e.g., vertical integration, mergers) (Lesser 1998, Enriquez 1998, Linder 1999).

Traditionally, most research was a result of public investment and the products of the research were public goods (Huffman and Evenson 1993). However, the establishment of enforceable IPRs creates an incentive for private investment because the inventor can extract the most of the economic rents from his investment by retaining ownership over the new technology. Consequently, research funding has changed for most crops (Malla, Gray and Phillips 1998; Malla and Gray 1999; Gray and Malla 2000; and Gray, Malla and Ferguson 2000). Over time, research has shifted from a modest public investment to large private investment. This funding shift is evident in the registration of new varieties. Prior to the 1970s most varieties were public, but now they are private. Finally, the public sector has further stimulated the growth in private investment by providing private research incentives (e.g., research grants, research subsidies, invest in infrastructure). The combined effect has been an increase in research investment by the private sector and very different rules for agricultural research.

The existing economic literature has not adequately addressed these issues. The contributions on the returns to agricultural research mainly examine the economic implications of public research investment in the absence of IPRs and under perfectly competitive market structure (for review and summary of this literature see Alston, Marra, Pardey and Wyatt 2000). A number of more recent studies examined R&D issues in an imperfectly competitive framework and show that while IPRs create incentives to invest they may also create market power and efficiency (deadweight) losses (e.g., Moschini and Lapan 1997, Fulton and Keyowski 1999, Alston, and Venner 2000). Several studies have examined whether public funded R&D substitutes for ("crowds out") privately funded R&D, or complements ("crowds in") private expenditure analytically (e.g., Warr 1982, Roberts 1984, Bergstrom et al., 1986) and empirically (e.g., Khanna et al., 1995, Khanna and Sandler 1996, Diamond 1999, Johnson and Evenson 1999). Steinberg (1993) and David, Hall and Toole (1999) provided a survey of the available empirical evidence and concluded that they results are inconclusive regarding the direction and the magnitude of the relationship between public and private research expenditure.

One other related issue is that most economic studies either do not distinguish between basic and applied research, or assume a linear *pipeline* relationship (e.g., Grilliches 1986, Adams 1990, Huffman and Evenson 1993, Thirtle et. al 1998). Recently, a few studies modeled the link between basic and applied research with more complexity and in some cases in a nonlinear manner (e.g., Rosenberg 1990 and 1991, Pavitt 1991, Brooks 1994, Dasgupta and David 1994, Pannell 1999, Rausser 1999). However, these papers tend to make assumptions about the relationship between basic and applied research.

Few research contributions model agricultural crop research as a search process in a very basic framework (e.g., Evenson and Kislev 1976). The search process allows us to recognize research as a stochastic process with sporadic outcomes, which is more consistent with the nature of the agricultural research process. Moreover, the search process allows us to account for the effect of basic research on applied research. The manner by which basic research affects applied agricultural research is embodied in the model. Hence, the available research contributions have not sufficiently addressed the economic issues of the contemporary R&D industry.

The goal of this thesis is to develop a broader understanding of how biotechnology, changes in IPRs and the resulting changes in industry structure have affected the private and public incentives for agricultural research. The specific objectives include to developed an analytical framework to examine: (1) the incentives for private R&D expenditure; (2) the spillovers between basic and applied research; (3) the spillovers between private and public research; (4) how the changes in IPRs affect private investment; and (5) how the firm's market size affects private investment; and an empirical examination the theoretical findings of this study. To achieve the objective of this paper, a stochastic analytical model within an imperfect competitive framework, which accounts for product differentiation and farmers heterogeneity, was developed.

The remainder of the paper is organized into three sections. Section 2 develops the analytical framework for this analysis, which is used to derive a number of propositions on the key economic issues. Section 3 presents the econometric analysis and the regression results of the model. Finally section 4 contains a summary and the concluding comments of the paper.

2. Theoretical Development of The Model

The behavior of the imperfectly competitive research firms is modeled in three stages. In the first stage, each firm (private and/or public) decides on the optimal number of research trials, which creates a differentiated variety with a specific expected yield. In the second stage, given this yield, each research firm chooses the price they will charge for the variety. In the third stage, farmers look at the prices and yields of the varieties and choose the varieties to purchase on the basis of net returns. The model is solved using backward induction. The framework developed captures essential elements of today's research industry: that is, the small number of research firms with market power selling differentiated products to heterogeneous farmers.

2.1 Exponential Distribution of the Largest Values

The search process is a sequence of independent experiments composed of n_t trials. Each trial is a test of specific traits or techniques that could increase the current yield. In a breeding program the crop breeders will typically cross two parent varieties and will use research trials to search among the offspring for the highest yielding genotype with desirable agronomic and quality characteristics. For simplicity, it is assumed that each trial results in a single observation or outcome (specific yield level); that is, one random draw from a population (the distribution of yield).[1] Hence, the control variable is the number of trials (the extent of experimentation) and the state variable is the current yield level. The outcome of the experiment is the observation in the sample that could most increase the current yield.

---

[1] In reality, a yield trial is often carried out with a number of replications. Experimental designs use replication (repeated plantings of the varieties) to minimize the variation of non-genetic factors (e.g., weeds, moisture) in the estimation of the potential yield.

To derive the expected value of the best observation in the sample, the n^{th} order statistic and the extreme value statistic is calculated (Gumbel, 1958; Epstein, 1960).

The model that follows is illustrated in terms of the exponential distribution. The exponential distribution is chosen mainly because it provides an explicit and tractable formula for determining the distribution of order statistics.[2] Moreover, the type of research the exponential distribution describes is typified in biological processes or crop research like canola and wheat (e.g., monotonically decreasing probability density function).

In terms of the exponential distribution, the expected value of the increase in yield is (Evenson and Kislev 1976):

$$(1) \qquad E_n(\Delta y) = \sum_{i=1}^{n} \frac{1-[1-e^{-\lambda(y-\theta)}]^i}{\lambda i}$$

Allowing n to be a continuous variable, the sum by integration is:

$$(2) \qquad E_n(\Delta y) = \int_{i=1}^{n} \frac{1-[1-e^{-\lambda(y-\theta)}]^i}{\lambda i}\, di$$

To take the derivative of the change in yield of the exponential distribution with respect to the number of trials, Leibnitz's Rule[3] is applied:

$$(3) \qquad \frac{\partial E_n(\Delta y)}{\partial n} = \frac{1-[1-e^{-\lambda(y-\theta)}]^n}{\lambda n}$$

---

[2] Generally, it is not easy to derive an explicit and tractable formula for the distribution of order statistics (Epstein, 1960).

[3] If $z = \int_{h(x)}^{g(x)} f(x,y)\,dy$ then $\frac{\partial z}{\partial x} = \frac{\partial g(x)}{\partial x} f(x,y)\Big|_{g(x)} - \frac{\partial h(x)}{\partial x} f(x,y)\Big|_{h(x)} + \int_{h(x)}^{g(x)} \frac{\partial f(x,y)}{\partial x} dy$

2.2 Third Stage: Farmers' Demand for the Variety

The development of the analytical model begins with the third stage, where the farmers' demand for the varieties is derived. There are *N* farmers. All farms are the same size, *k* acres, and each farmer (*i*) has homogeneous land with a unique characteristic ψ_i (e.g., soil quality, weed infestation, management skills) that varies across farms.[4] To simplify the analysis, the characteristic ψ_i uniformly distributed between 0 and 1. Farmers purchase either variety *A* or variety *B* from firm *A* or *B* respectively.[5] Variety *A* is best suited to farmers for land characteristic $\psi_i=0$ while variety *B* is best suited for $\psi_i=1$. The modeling framework accounts for the case of complete and incomplete property rights. It is assumed that the private firms are risk neutral,[6] which may accurately reflect the investment behavior of the very large, diversified multinational firms involved in crop research today. It is also implicitly assumed in the model that there are no terms of trade effects (i.e., a small country assumption), and the output price, *p* is exogenously defined.

---

[4] Alternatively, *k* could represent a uniform field size, such that each farmer could operate several fields making separate variety decisions on each field of quality ψ_i.

[5] Having a fixed amount of crop area to be allocated between varieties is consistent with a crop that is constrained by rotational considerations. An alternative specification, which allows for substitution between this crop and others as well as between varieties would complicate the demand relationships and make the pricing decision of the two firms more complex. With this additional complexity, determining the private equilibrium outcomes and the optimal public policy would be more difficult or even intractable.

[6] When the decision maker is risk-averse, risk considerations will affect the amount of research the research firm is undertaking. The risk-averse decision maker is likely to carry out more research trials than a risk-neutral decision maker given the risk-reducing effect of extra experiments in the sense that the variance of the n^{th} order statistic (the maximum value of an experiment) in most cases declines, the more trials the breeding firm is undertaking (Sunding and Zilberman, 2000).

The objective of each farmer *i* is to maximize profit by selecting variety *A*, ϕ_i , or variety *B*, $1-\phi_i$,[7] subject to the inequality constraint $0 \leq \phi_i \leq 1$. It can be written as:

(4) $$\underset{\phi_i}{Max}\ \Pi_i = sp[\Delta y^A+\tau(1-\psi_i)]k\phi_i - k\phi_i\ w^A + sp[\Delta y^B+\tau\psi_i)]k(1-\phi_i) - k\,(1-\phi_i)\ w^B \qquad s.t.\quad 0 \leq \phi_i \leq 1$$

where:

k = the area seeded by each farmer

ϕ_i = the proportion of area seeded to variety *A*

w^A = the price of seed of variety *A*

w^B = the price of seed of variety *B*

p = the price of output

ψ_i = the land characteristic of farmer *i*

τ = the change in yield associated with a unit change in the differential attribute[8]

$\Delta y^A+\tau(1-\psi_i)$ = the expected yield of variety *A* for producer of characteristic ψ_i

$\Delta y^B+\tau\psi_i$ = the expected yield of variety *B* for producer of characteristic ψ_i

s = the proportion of the value generated from the variety that a farmer is willing to pay in the market place to purchase the variety directly from the breeding firm ($0 \leq s \leq 1$)[9]

---

[7] Every producer, except one where $0 < \phi < 1$, is at a corner point.

[8] The assumption of heterogeneity can be relaxed in the modeling framework by reducing τ towards zero, making the two varieties nearly perfect substitutes for one another. In the case of perfect substitutes, τ would be equal to zero and internal solutions involving two firms would be indeterminate. This is a perfect competition case, where price is equal to marginal cost and the firm's profits would be equal to zero.

[9] For instance, when $s<1$ farmers' opportunity cost of not purchasing the variety directly from the breeding firm is low because they have other ways to obtain the seed (e.g., the "brown bag" market). Hence, they are willing to pay something less than the full value of the variety to breeding firm, which represents the case of incomplete IPRs. Fully appropriation of R&D benefits occur when s=1.

The value of $\hat{\psi}_i$ --which is the land quality of a farmer who is indifferent between variety *A* or *B* -- can be computed mathematically by solving the following equation:

(5) $s\Delta y^A + sp\tau - sp\tau\hat{\psi}_i - w^A = sp\Delta y^B - sp\tau\hat{\psi}_i - w^B$, or:

(6) $$\frac{[\Delta y^A - \Delta y^B + \tau] - w^A + w^B}{2\tau} = \hat{\psi}_i$$

All farmers with land quality less than $\hat{\psi}_i$ purchase variety *A*, while all farmers with land quality greater than $\hat{\psi}_i$ purchase variety *B*. Given that $\hat{\psi}_i$ is uniformly distributed between 0 and 1, then the market share of variety *A* is defined by $\hat{\psi}_i$.

The demand for variety *A* is equal to the product of the number of farmers, the amount of acreage each farmer has, and the market share for variety *A* ($Q^A = Nk\hat{\psi}_i$). Given that we choose units of quantity such that *Nk* is equal to 1, then the demand for variety *A* is equal to the market share for variety *A* ($Q^A = \hat{\psi}_i$). As is shown in equation 6, the demand for variety *A* is an increasing function of its own yield and the other price and a decreasing function of its own price and the other yield, and the overall responsiveness is in proportion to the total seeded acreage and is inversely related to τ, the yield differential per change in unit of land quality.

2.3 Second Stage: Pricing of the Varieties

Having estimated farmers' demand for varieties *A* and *B*, the optimal pricing by firms *A* and *B* can be derived. A model with differentiated goods and a Nash equilibrium in prices is used to model the duopoly. The firms do not charge at marginal cost because they face a downward-sloping demand for their products, which is a function of their own price and the price charged by the rival. As mentioned previously, research firms *A* and *B* sell differentiated varieties to a group of heterogeneous farmers. At the Nash equilibrium, neither firm can achieve a higher profit by changing the price charged for its product. The firms operate in a single period and pick a price level[10], where marginal revenue of the residual demand facing each firm from the sale of their variety is equal to the marginal cost of marketing and reproducing the seed. The objective of firm *A* is to maximize its profits, which is:

$$(7) \qquad Max\ \Pi^A = w^A \hat{\psi}_i - L\hat{\psi}_i$$

where L= marginal cost of marketing and reproducing of the seed

The first-order condition (F.O.C) for this problem is:

$$(8) \qquad \frac{\partial \Pi^A}{\partial w^A} = \frac{sp[\Delta y^A - \Delta y^B + \tau] - w^A + w^B}{2\tau sp} - \frac{w^A}{2\tau sp} + \frac{L}{2\tau sp} = 0$$

Solving for seed price w^A and w^B, the best-response function of firm *A* and *B* can be computed and these are given by:

$$(9) \qquad w^A = \frac{sp[\Delta y^A - \Delta y^B + \tau] \ + L}{2} + \frac{1}{2} w^B$$

$$(10) \qquad w^B = \frac{sp[\Delta y^B - \Delta y^A + \tau] \ + L}{2} + \frac{1}{2} w^A$$

Substituting firm *B's* best-response function w^B into firm *A's* best-response function, the Nash equilibrium can be determined. At the Nash equilibrium, the price charged by firm *A* is equal to w^{A*}, while for firm *B* it is equal to w^{B*}.

---

[10] It is assumed that price is the strategic variable of the research firms.

$$(11) \qquad w^{A*} = \frac{sp[\Delta y^A - \Delta y^B]}{3} + sp\tau + L$$

$$(12) \qquad w^{B*} = \frac{sp[\Delta y^B - \Delta y^A]}{3} + sp\tau + L$$

The optimal price charged (w^{A*} and w^{B*}) is a function that increases in proportion to the present value of the future stream of benefits the firms can capture. Hence, the more appropriable the research benefits are, the more firms charge for the variety they developed.

Having estimated the Nash pricing for firm *A* and firm *B*, the reduced form for the optimal market share for variety *A* can be estimated by substituting w^{A*} and w^{B} for $\hat{\psi}_i$, which gives:

$$(13) \qquad \psi_i^* = \frac{[\Delta y^A - \Delta y^B]}{6\tau} + \frac{1}{2}$$

The optimal market share for variety *A* (or the fraction of farmers purchasing variety *A*) is an increasing function of the difference between expected yield of variety *A* and variety *B*. The response of ψ_i^* to a change in the expected yields is a decreasing function of τ, the degree of heterogeneity of producers.

2.4 First Stage: Optimal Investment

In this section, the optimal research investment for firm *A* and firm *B* is derived given farmers' demand for the varieties and the optimal pricing of the varieties by the firms. In this normative approach, the optimal search behavior is estimated as the difference between the expected gain from the search and the cost of the search (e.g., Stigler 1961; Nelson 1970). Specifically, given the farmer's demand for the varieties and the optimal pricing of those varieties, firms will determine the extent of their experimentation, which is the optimal number of research trials (control variable). The indirect profit function for firm *A* is defined as:

(14) $\Pi^A = w^A \psi_i^* - L^* \psi_i$

More explicitly, the indirect profit function is equal to:

(15)

$$\Pi = \left\{ \frac{p[E(\Delta y^A) - E(\Delta y^B)]}{3} + p\tau + L \right\} \left\{ \frac{[E(\Delta y^A) - E(\Delta y^B)]}{6\tau} + \frac{1}{2} \right\} - L \left\{ \frac{[E(\Delta y^A) - E(\Delta y^B)]}{6\tau} + \frac{1}{2} \right\} =$$

$$\frac{1}{18} \frac{sp[E(\Delta y^A)^2 - 2E(\Delta y^A)E(\Delta y^B) + 6E(\Delta y^A)\tau + E(\Delta y^B)^2 - 6\tau E(\Delta y^B) + 9\tau^2]}{\tau}$$

Firm *A*'s objective is to choose the number of trials that maximizes its indirect profit function while it considers the cost of the experimentation. Hence, the problem firm *A* faces is:

(16) $\underset{n^A}{Max}\, \Pi^A(n) =$

$$\frac{1}{18} \frac{sp[E(\Delta y^A)^2 - 2E(\Delta y^A)E(\Delta y^B) + 6E(\Delta y^A)\tau + E(\Delta y^B)^2 - 6\tau E(\Delta y^B) + 9\tau^2]}{\tau} - c^A n$$

The first-order condition (FOC) for firm *A* is:

(17) $$\frac{\partial \Pi}{\partial n^A} = \frac{1}{18} \frac{sp[2\frac{\partial E(\Delta y^A)}{\partial n^A} E(\Delta y^A) - 2\frac{\partial E(\Delta y^A)}{\partial n^A} E(\Delta y^B) + 6\frac{\partial E(\Delta y^A)}{\partial n^A}\tau]}{\tau} - c = 0$$

Assuming that firms *A* and *B* are identical in the sense that they have the same cost of experimentation and the same expected change in yield, then the FOC for firm *B* is the mirror image of that for firm *A*:

(18) $$\frac{\partial \Pi}{\partial n^B} = \frac{1}{18} \frac{sp[2\frac{\partial E(\Delta y^B)}{\partial n^B} E(\Delta y^B) - 2\frac{\partial E(\Delta y^B)}{\partial n^B} E(\Delta y^A) + 6\frac{\partial E(\Delta y^B)}{\partial n^B}\tau]}{\tau} - c = 0$$

Additionally, given that $E(\Delta y^A) = E(\Delta y^B)$ (by the symmetry assumption) the FOCs for firm *A* and firm *B* collapse to:

(19) $$\frac{\partial \Pi}{\partial n^A} = \frac{1}{3} sp[\frac{\partial E(\Delta y^A)}{\partial n^A}] - c \ = 0 \text{, or , } \frac{1}{3} sp[\frac{\partial E(\Delta y^A)}{\partial n^A}] = c$$

(20) $$\frac{\partial \Pi}{\partial n^B} = \frac{1}{3} sp[\frac{\partial E(\Delta y^B)}{\partial n^B}] - c \ = 0 \text{, or , } \frac{1}{3} sp[\frac{\partial E(\Delta y^B)}{\partial n^B}] = c$$

Using the exponential distribution, the FOC for firm *A* is (see section 2.1):

(21) $$\frac{\partial \Pi}{\partial n^A} = \frac{1}{3} \frac{sp\{1 - [1 - e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda n^A} - c = 0, \text{ or } \frac{1}{3} \frac{sp\{1 - [1 - e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda n^A} = c$$

This condition states that the expected profits from R&D search are maximized when the marginal values of the expected benefits are equal to marginal costs. Finally, the second-order condition (SOC) with respect to the number of trials, hereafter referred to as H, is less than zero for maximization problem:

(22) $$\frac{\partial^2 \Pi}{\partial n^{A^2}} = -\frac{1}{3} \frac{sp[1 - e^{-\lambda(y-\theta)}]^{n^A} \ln[1 - e^{-\lambda(y-\theta)}]}{\lambda \ n^A} - \frac{1}{3} \frac{sp\{1 - [1 - e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda \ n^{A^2}} = \mathbf{H} < 0$$

2.5 Propositions Regarding the Effect Exogenous Variables

Given the nature of the expression, we were unable to estimate a closed-form solution for n^A. Hence, the Implicit Function Theorem is applied to determine the effect of the exogenous variables on the number of trials the firm is undertaking. The relationship between the exogenous (policy) variable and the optimal level of private research *n* is derived in the form of propositions.

Proposition 1**:** *A decrease in the marginal cost of experimentation will increase the number of research trials and the private firm's R&D search.*

Proof:

$$(23)\qquad \frac{dn^A}{dc} = -\frac{\dfrac{\partial^2\Pi}{\partial n^A \partial c}}{\dfrac{\partial^2\Pi}{\partial n^{A^2}}} = -\frac{-1}{\mathbf{H}} < 0$$

The denominator of the above comparative static is the SOC of the expected profit maximization (from equation 22) and therefore is negative in sign. The numerator of the above expression represents the change in the marginal benefit of the research investment with respect to the cost of the experimentation, which is negative in sign. Hence, the cost of the trials negatively affects the number of trials that are undertaken. This result also shows that government policy which reduces the firm's per-unit cost of trials would increase the optimal amount of research undertaken.

Proposition 2: *An increase in the output price (the price that farmers receive for their crop) increases the private firm's R&D search and applied research expenditure.*

***Proof*:**

$$(24)\qquad \frac{dn^A}{dp} = -\frac{\dfrac{\partial^2\Pi}{\partial n^A \partial p}}{\dfrac{\partial^2\Pi}{\partial n^{A^2}}} = -\frac{\dfrac{1}{3}\dfrac{\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\, n^A}}{\mathbf{H}} > 0$$

The numerator of the above expression represents the change in the marginal benefit of the research investment with respect to the output price. Given that $0<e^{-x}<1$, and that $\lambda>0$, $z>0$, $y>0$, then $0 < 1-[1-e^{-\lambda(y-\theta)}]^{n^A} < 1$, which results in a numerator that is positive in sign. From the SOC, the denominator is negative in sign. Hence, the output price positively affects the number of trials. An increase in the area of crop would have the same effect as an increase in the price of the product and would increase the amount of private investment in research. This also suggests that low-value crops and those grown on small areas would attract little private research funding.

The following two propositions examine the relationship between basic research and applied research. Basic research can affect the distribution of R&D outcomes for a given R&D activity. For the exponential distribution, basic research can affect the parameters λ and θ. As stated above the mean of the exponential is $\theta + 1/\lambda$ and the variance is $1/\lambda^2$. Basic research could increase θ thereby increasing the lower bound and the mean of the distribution without affecting variance, or basic research could reduce λ which would simultaneously increase the mean and the variance of the distribution. Both of these effects of basic research are examined in the propositions to follow. These two propositions show that basic research causes a "crowding in" of applied research.

Proposition 3**:** *Basic research that either increases the lower bound or the mean of the potential yield distribution will increase the number of the private firm's R&D search and applied research expenditure.*

Proof:

$$(25) \qquad \frac{dn^A}{d\theta} = -\frac{\dfrac{\partial^2 \Pi}{\partial n^A \partial \theta}}{\dfrac{\partial^2 \Pi}{\partial n^{A^2}}} = -\frac{\dfrac{1}{3}\dfrac{p[1-e^{-\lambda(y-\theta)}]^{n^A} e^{-\lambda(y-\theta)}}{[1-e^{-\lambda(y-\theta)}]}}{\mathrm{H}} > 0$$

The numerator of the above comparative static is positive in sign given that $0 < 1-[1-e^{-\lambda(y-\theta)}]^{n^A} < 1$. Moreover, from the SOC the denominator is negative in sign. Hence, the whole fraction is positive, which means that there is a positive relationship between basic research that shifts the lower bound and the mean of the distribution and applied research. Put differently, a firm invests more in R&D when more basic research is available.

The intuition behind this is illustrated in Figure 1. Figure 1 represents the probability function of the n^{th} order statistics for the exponential distribution. Parameter y shows the current yield level (state variable), while parameter θ denotes the accumulation of scientific knowledge attributable to basic research or, in statistical language, θ is the lower bound of the exponential distribution. Note that the distribution is bounded from below ($\theta>0$), which allows for a positive minimum guaranteed yield level. When the stock of scientific knowledge increases, the parameter θ is increased to θ', which in turn increases the mean of the probability distribution over all the possible yield levels as the distribution curve shifts to the right. As mentioned earlier, the probability of inventing a variety that has higher yield than the current one based on a random draw is measured by the area to the right of the current yield level (y). Hence, the rightward shift of the probability function, with a given current yield level, improves the probability (or the expected values) of inventing a higher-yielding variety than the current one as the area to the right of y increased. Therefore, the expected benefits of a trial increase, which increases the optimal amount of private research.

[Figure 1]

Proposition 4**:** *Basic research that reduces the parameter λ in the exponential distribution, thereby increasing the variance and the mean of the exponential distribution, will increase the private firm's R&D search and applied research expenditure.*

Proof*:*

(26)

$$\frac{dn^A}{d\lambda} = -\frac{\dfrac{\partial^2\Pi}{\partial n^A \partial\lambda}}{\dfrac{\partial^2\Pi}{\partial n^{A^2}}} = -\frac{\dfrac{1}{3}\dfrac{p[1-e^{-\lambda(y-\theta)}]^{n^A}(-y+\theta)e^{-\lambda(y-\theta)}}{[1-e^{-\lambda(y-\theta)}]\ \lambda} - \dfrac{1}{3}\dfrac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda^2 n^A}}{\mathbf{H}} < 0$$

The first fraction at the numerator of the above comparative static result is positive in sign and the second one is negative in sign since $0 < 1-[1-e^{-\lambda(y-\theta)}]^{n^A} < 1$. Moreover, from the SOC the denominator is negative in sign. Consequently, the above comparative static result is negative in sign, or a decrease in λ increases the number of trials (*n*). Hence, an increase in the amount of basic research, which reduces λ, acts to increase the optimal amount of private applied research.

Basic research increases the probability and expected value of inventing a variety yielding higher than the current one. If this is modeled through a reduction in λ then both the mean and the variance of the distribution increase without changing the lower bound. The effect of a change in λ is depicted in Figure 2. The increase of the variance and the mean of the population sample (parameter λ), given that the lower bound of the distribution (parameter *θ*) and the current technology level (parameter *y*) remain constant, change the shape of the distribution. The new distribution shifts to the right and becomes flatter, which results in an increase in the area to the right of *y*. Hence, by increasing the variance and the mean of the probability distribution function, the likelihood (or probability) of inventing a variety with a yield level higher than the current one is increased. This increases the expected benefits of a trial, thereby increasing the optimal amount of private research.

[Figure 2]

Proposition 5**:** *For any given potential yield distribution, a higher current technology level will reduce the private firm's R&D search and applied research expenditure.*

Proof:

$$(27)\qquad \frac{dn^A}{dy} = -\frac{\dfrac{\partial^2 \Pi}{\partial n^A \partial y}}{\dfrac{\partial^2 \Pi}{\partial n^{A^2}}} = -\frac{-\dfrac{1}{3}\dfrac{p[1-e^{-\lambda(y-\theta)}]^{n^A}\, e^{-\lambda(y-\theta)}}{[1-e^{-\lambda(y-\theta)}]}}{\mathbf{H}} < 0$$

The numerator of the fraction at the above comparative static result is negative in sign since $0 < 1-[1-e^{-\lambda(y-\theta)}]^{n^A} < 1$. Moreover, from the SOC the denominator is negative in sign. Hence, the sign of the whole is negative, which means that a change in current technology level *y* will lead to a same-direction change in the optimal number of trials firms undertake.

Firms have less incentive to devote more resources to R&D when the current technology level, (*y*) is very high. In statistical terms, the increase in the current technology level shifts *y* to the right in the distribution (see Figure 3). This, in turn, reduces the area that measures the probability of inventing a better variety (area to the right of *y*). Hence, the rightward shift *y* (current technology level) reduces the likelihood of inventing a higher-yielding variety. This means that a higher existing technology reduces the expected return from an investment.

[Figure 3]

The following proposition examines the relationship between applied public research and applied private research. It was shown that public basic research enhances the effectiveness of applied research because basic and applied researches are treated as complements. However, when both public and private firms are engaged in applied research, their research is a substitute for each other's.

Until this point two private firms in the industry were modeled. For the analysis that follows, one of the firms *B* is public and firm *A* private. The public firm autonomously chooses the level of research investment and the other firm reacts to this increasing expenditure as given by the reaction function in Section 2.3. Once the public firm has made the autonomous research decision, it prices its product in a way similar to private firms as described above (Section 2.3). This may be reasonable assumption given that many public institutions sell or give their varieties to private firms for marketing.[11]

Proposition 6**:** *Applied public research "crowds out" applied private research expenditure -- i.e., an increase in public applied research expenditure reduces the private firm's R&D search and applied research expenditure.*

Proof**:**

The FOC for firm *A* of the optimal investment problem is:

$$(28) \qquad \frac{\partial \Pi}{\partial n^A} = \frac{1}{18} \frac{P[2\dfrac{\partial \mathrm{E}(\Delta y^A)}{\partial n^A}\mathrm{E}(\Delta y^A) - 2\dfrac{\partial \mathrm{E}(\Delta y^A)}{\partial n^A}\mathrm{E}(\Delta y^B) + 6\dfrac{\partial \mathrm{E}(\Delta y^A)}{\partial n^A}\tau]}{\tau} - c = 0$$

Total differentiating the FOC in equation (21) with respect to endogenous n^A and the exogenous n^B and applying the Implicit Function Rule to produce the comparative static derivative dn^A/dn^B, this gives:

---

[11] An alternative would be to model the pricing of product of the public firm equal to average cost. Although we do not explicitly model this situation, this type of behavior would further reduce private incentives for research investment.

(29)

$$\frac{dn^A}{dn^B} = \frac{\frac{2p\tau}{18}\frac{\partial E(\Delta y^A)}{\partial n^A}\frac{\partial E(\Delta y^B)}{\partial n^B}}{\frac{2p\tau}{18}E(\Delta y^A)\frac{\partial^2 E(\Delta y^A)}{\partial n^{A^2}} + \frac{2p\tau}{18}\frac{\partial E(\Delta y^A)}{\partial n^A}\frac{\partial E(\Delta y^A)}{\partial n^A} - \frac{2p\tau}{18}E(\Delta y^B)\frac{\partial^2 E(\Delta y^A)}{\partial n^{A^2}} + \frac{6p}{18}\frac{\partial^2 E(\Delta y^A)}{\partial n^{A^2}}} < 0$$

Note that the denominator of the above comparative static is negative in sign while the numerator is positive. Consequently, the whole fraction is negative in sign, which means that an increase in the public applied research negatively affects the quantity of private applied research. To put it differently, the more applied research the public sector invests in, the less applied research the private sector undertakes.

If we consider a small deviation from the symmetric equilibrium where $E(\Delta y^A)=E(\Delta y^B)$, equation 29 is reduced to $\frac{dn^A}{dn^B} = -\frac{1}{1+3\tau}$. When $\tau=0$, meaning that the two varieties are identical, then the above equation is equal to $\frac{dn^A}{dn^B} = -1$, which implies that public applied research investment completely “crowds out” private research. However, when $\tau>0$, (the varieties are differentiated) then the ratio $\frac{dn^A}{dn^B}$ is negative but less than one in absolute value. In this case there is an incomplete “crowding out” effect. Consequently, public applied research is a substitute for (“crowds out”) applied private research regardless of the degree of product differentiation.

The following propositions examine the relationship between product differentiation and applied research. The first proposition deals with the effect of product differentiation on the private applied research expenditure. The second proposition shows that product differentiation increases the prices charged for varieties, indicating an increase in market power.

Proposition 7:

(a) An increase in product differentiation τ will not change the private firm's R&D search and applied research expenditure.

(b) When product differentiation τ is increased, the price charged to the farmers is increased, while costs do not increase indicating an increase in the market power of firms.

***Proof*:**

Part (a)

$$(30) \qquad \frac{dn^A}{d\tau} = \frac{\dfrac{\partial^2 \Pi}{\partial n^A \partial \tau}}{\dfrac{\partial^2 \Pi}{\partial {n^A}^2}} = \frac{0}{\mathbf{H}} = 0$$

Note that from the SOC the denominator of the above comparative static is negative in sign. The numerator represents the change in the marginal benefit of research investment with respect to product differentiation (parameter τ). Given that the numerator is zero, the whole fraction is zero. Consequently, the R&D search intensity (number of trials) and in turn the investment in research the firm undertakes does not change with an increase in product differentiation.

Part (b)

Given that $\frac{dn^A}{d\tau} = 0$, then $\frac{\partial E(\Delta y^A)}{\partial \tau} = 0$ and $\frac{\partial E(\Delta y^B)}{\partial \tau} = 0$. Consequently, the total derivative of $w^{A*} = \frac{p[E(\Delta y^A) - E(\Delta y^B)]}{3} + p\tau + L$ with respect to τ is equal to the partial derivative of w^{A*} with respect to τ, which yields:

$$\frac{dw^{A*}}{d\tau} = \frac{\partial w^{A*}}{\partial \tau} = p > 0 \tag{31}$$

Hence, from the above comparative static, it can be concluded that τ positively affects w^A. In other words, the firms with the greater product differentiation can charge a higher price to the farmers. The ability of the firm to charge a higher price for its variety while doing the same amount of R&D, indicates an increase in market power. Consequently, product differentiation also increases a firm's profits at the expense of farmer welfare.

Proposition 8: *An increase in the intellectual property rights will increase the private firm's R&D search and applied research expenditure.*

Proof:

(32)

$$\frac{dn^A}{ds} = -\frac{\frac{\partial \Pi}{\partial s}}{\frac{\partial \Pi}{\partial n^A}} = -\frac{\frac{1}{3}\frac{\mathrm{p}\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\, n^A}}{-\frac{1}{3}\frac{sp[1-e^{-\lambda(y-\theta)}]^{n^A}\ln[1-e^{-\lambda(y-\theta)}]}{\lambda\, n^A} - \frac{1}{3}\frac{sp\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\, n^{A^2}}} > 0$$

Note that the denominator of the above comparative static is the SOC of the expected profit maximization and is therefore negative in sign. The numerator of the above expression represents the change in the marginal benefit of the research investment with respect to *s*. Given that $0<e^{-x}<1$, and that $\lambda>0$, $z>0$, $y>0$, then $0<1-[1-e^{-\lambda(y-\theta)}]^{n^A}<1$, and the numerator will have a positive sign. Hence, an increase in IPRs, *s*, will increase the private firm's R&D search and applied research expenditure. Put differently, a firm invests more in R&D, the more appropriable the research benefits are.

The intuition behind the above result is as follows. As shown, when $s=1$ the property rights are complete and the private demand for purchasing the variety is equal to the social or total demand for the variety. An example in this case is a hybrid variety. Farmers have to buy the seed every year in order to have the desirable traits so the research firm can fully extract all the future benefits from the hybrid varieties. As a result, the firm invests more in R&D. In the intermediate situation, where $0<s<1$, the breeding firm can extract only part of the benefits provided to farmers. An example is herbicide-tolerant varieties or designer varieties. A breeding firm can extract the benefits the first year the farmers buy that varieties but the future benefits are uncertain. In subsequent years farmers may decide to reproduce their own seed. Hence, breeders are unwilling to make the same investment, knowing only part of their investment cost can be recouped. Finally, when $s=0$ no economic rent can be extracted from farmers, which in turn results in a very small R&D investment.

The following proposition examines the relationship between a firm's market size and the amount of investment in agricultural research. Since the writings of Schumpeter (1934), numerous studies, mainly empirical, have been conducted to investigate the effect of firm's size on R&D intensity.[12] The results of those studies are controversial. In the analysis that follows, the theoretical model developed in the previous section was modified to examine this issue. It is assumed that farmers prefer variety *A* to variety *B*, so they are willing to pay more for variety *A* for any given level of Δy^A, Δy^B and w^B and less for variety *B*. Given increased demand for variety *A*, the share of firm *A* is increased which increases the market size of that firm, while the opposite outcome holds for firm *B*. The FOC under this scenario for firm *A* is equal to: (33)

$$\frac{\partial \Pi^A}{\partial n^A} = \frac{1}{18}\frac{p[2\frac{\partial E(\Delta y^A)}{\partial n^A}E(\Delta y^A) - 2\frac{\partial E(\Delta y^A)}{\partial n^A}E(\Delta y^B) + 6\frac{\partial E(\Delta y^A)}{\partial n^A}\tau]}{\tau} + \frac{p\frac{\partial E(\Delta y^A)}{\partial n^A}m}{9} + \frac{\frac{\partial E(\Delta y^A)}{\partial n^A}m}{9\tau} - c = 0$$

where *m* denotes the increase of the producers' willingness to pay for variety *A* and the reluctance of the producers' willingness to pay for variety *B*.

Proposition 9: *An increase in a firm's market size will increase the private firm's R&D search and applied research expenditure.*

Proof:

(34)
$$\frac{dn^A}{dm} = -\frac{\frac{\partial \Pi^A}{\partial m}}{\frac{\partial \Pi^A}{\partial n^A}} = -\left\{\frac{\frac{1}{9}\frac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\, n^A}}{A} + \frac{\frac{1}{9}\frac{\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\tau\lambda n^A}}{A}\right\} > 0$$

---

[12] Schumpeter (1934), in his early work, argued that the small-scale entrepreneur is the main factor in capitalism's vitality. However, he changed his beliefs by the beginning of the 1940s. In 1942 he stated that "large-scale enterprise has come to be the most powerful engine of [economic] progress" (Schumpeter 1942, p. 24). Since then a lot of economists have provided evidence in both directions,

where *A* is:

$$
\begin{aligned}
A = &-\frac{1}{3}\frac{p[1-e^{-\lambda(y-\theta)}]^{n^A}\ln[1-e^{-\lambda(y-\theta)}]}{\lambda\, n^A}-\frac{1}{3}\frac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\, n^{A^2}}- \\
&\frac{1}{9}\frac{p[1-e^{-\lambda(y-\theta)}]^{n^A}\ln[1-e^{-\lambda(y-\theta)}]m}{\lambda\, n^A}-\frac{1}{9}\frac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}m}{\lambda\, n^{A^2}}- \\
&\frac{1}{9}\frac{[1-e^{-\lambda(y-\theta)}]^{n^A}\}\ln[1-e^{-\lambda(y-\theta)}]m}{\tau\lambda\, n^A}-\frac{1}{9}\frac{\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}m}{\tau\lambda\, n^{A^2}}
\end{aligned}
\tag{35}
$$

Note that the denominator of the above comparative static *A* for both fractions is the SOC of the expected profit maximization and is therefore negative in sign. The numerator of the above expression represents the change in the marginal benefit of the research investment with respect to *m*. Given that $0<e^{-x}<1$, and that $\lambda>0$, $z>0$ and $y>0$, then $0<1-[1-e^{-\lambda(y-\theta)}]^{n^A}<1$, and the numerator of both fractions are positive in sign. Hence, the sign of the comparative static is positive.

From the above comparative static result, it can be concluded that the higher the value of *m*, the more research trials the research firm undertakes. In other words, the bigger the market share of the firm, the more intense the R&D search which results in a bigger investment in research. Hence, with an increase in the market size, the firm applies more effort to each approach of innovation, which in turn increases the probability of inventing a breakthrough technology. As a result the expected value of the change in yield is increased.

2.6 Conclusions Regarding the Theoretical Model

A economic framework that modeled imperfectly competitive firms using a search process to improve the yield of differentiated varieties that are sold to

---

with the predominant finding that, "in most industries, above a modest threshold firm size large firms are no more research intensive than smaller firms" (Cohen and Klepper 1992, p.1).

heterogeneous farmers has created a tractable model of investment, pricing and adoption. The model, which reflect many of the features of today's biotech industry, was useful in deriving a number of interesting and intuitively appealing comparative static results.

3. A Study of the Private R&D Expenditures in Canola Crop Research in Canada

As a form of validation, this section uses the empirical evidence from the rapeseed/canola industry in Canada to examine some of the theoretical relationships derived in the previous section. The canola research sector was selected for this empirical analysis because this industry has attracted significant private research investment and has undergone many changes, including the recent introduction of biotechnology and changes in Intellectual Property Rights (IPR). Importantly, the data required for the analysis was also available due to the cooperation of private industry, public research institutions, and the personnel who manage the Inventory of Canadian Agricultural Research (ICAR) database.

3.1. Overview of R&D Effort

The development of the canola industry and the transformation of canola oil from a lubricant to a premium edible oil are the result of extensive genetic research in Canada. At the beginning of the 1960s, rapeseed/canola was a minor crop, and no canola crushing industry existed. By the beginning of 1990s, due to extensive research, canola had become a major crop and a large industry had been built around it. In Canada, canola is probably the most recent and pronounced example of how research and development can improve the comparative advantage of an industry (Malla, Gray, and Phillips 1998).

The funding of canola research in Canada has undergone many changes since its inception in the mid-1950s when Agriculture Canada began a program to improve the palatability of the oil. Over time, research shifted from a modest public research program to a large research industry dominated by private sector participation. In 1970, 83 per cent of the total research spending on canola R&D ($18 million) was public investment, while 17 per cent was private investment. Ten years later, research investment was 69 per cent public versus 31 per cent private. By 1999, the private sector's share had grown to 70 per cent of the total $149 million expenditure (Canola Research Survey 1999).

This funding shift is also evident in the registration of new varieties. Prior to 1973 all varieties (13 varieties) were public, while in the 1990-98 period 86 per cent of the varieties (162 varieties) were private (Canola Council of Canada 1998, CFIA (Canadian Food Inspection Agency) 1998). This large shift in research shares is a result of the large increase in private sector investment rather than a reduction in public research.

The change in the funding of research has coincided with a change in the nature of this R&D and the ownership of the property rights to the research and, implicitly, who captures the benefits from the investment (Canola Council of Canada 1998, Malla, Gray and Phillips 1998). Prior to 1990, all canola varieties were open-pollinated and non-transgenic, and were not protected by the Plant Breeders Right's Act, 1990 (Department of Justice 2000). This meant that virtually all of the acreage was grown without a production agreement and producers had the right to retain production for future seed use and to sell non-registered seed to neighbors. In contrast, by 1999, about 70 per cent of the canola acreage was seeded either to herbicide-tolerant (HT) varieties, which require annual technology use agreements or the use of specific herbicide, or hybrid varieties, which require annual purchase of the seed to retain the desirable traits. Without the ability of producers to retain production for seed, plant breeders are now in a far better position to capture value from genetic innovation. Thus, biotechnology and changes in the IPRs have influenced the incentive for private research.

Over time, the R&D effort for canola has shifted from modest public research investment to large, mainly private, investment. This funding change is also evident in the registration of new varieties. In the 1970s, all canola varieties were public, while now most of the canola varieties are privately owned. Hence, the transformation of canola research sector provides a rich set of data to empirically examine factors that influence private research investment.

3.2. Econometric Analysis

The regression analysis that follows uses a reduced form of the theoretical model to examine whether the empirical evidence in canola research is consistent with the theoretical framework developed in the previous section. It was not possible to develop a structural model, in large part due to the lack of detailed cross-sectional data. The propositions derived in the previous section identify how a number of exogenous variables affect private applied research investments. Hence, the selection of the exogenous variables in the model was based on the theoretical model developed in the previous section and the general economic theory. Table 1 outlines each of the exogenous variables used in the empirical model and identifies which proposition they are related to, and the hypothesized direction of the effect these variables will have on private applied research expenditure. These variables make up the general form of the model that is then subjected to a number of time series and specification tests.

To determine an adequate specification of the model, the time-series properties of the variables in the model were examined. To avoid any spurious relationship between the dependent and independent variables due to a unit root problem, individual series were tested for the presence of a unit root (i.e., $I(1)$). The appropriate lag and lead lengths for a number of variables was determined by the AIC (Akaike Information Criterion). The preliminary ADF test revealed that a unit root hypothesis could not be rejected in favor of a stationary one for almost all the variables [except the variable of the area seeded of canola crop which is $I(0)$] when it is measured in “level”. Furthermore, the variable for private research expenditure is $I(2)$; in other words, it has two unit roots (since the ADF test rejected the unit root hypothesis when taking the second difference). Hence, a model specified “in level” or in first difference could result in a spurious estimate with little reliability. Given the above findings about the nature of the series, the data were monotonically transformed by taking the logarithm of the series. The log-linear model (or constant elasticity form) was selected because this is the most commonly used functional form, is very tractable and intuitively appealing (the regression coefficients can be interpreted in terms of elasticities). After we transformed the series, the ADF tests were carried out and shown that all the variables are $I(1)$ [with the exception of the private area and the Plant Breeders Rights dummy which are $I(0)$]. Taking the first difference of the logarithmic series and performing the ADF test again, we found that the unit root hypothesis was rejected in favor of the stationary one. Consequently, the series were specified in a logarithmic form as a first difference[13].

To determine the variables that affect the private research investment and the extent of that effect, we estimated the general regression of the form:

$$(36)\ \mathrm{dln}prc_t = \beta_0+\beta_1 t + \beta_2 d\mathrm{ln}pca_{t-i}+\beta_3 d\mathrm{ln}pcb_{t-i}+\beta_4 d\mathrm{ln}ti_{t-i}+\beta_5 d\mathrm{ln}pri_t+\beta_6 d\mathrm{ln}pi_t+\beta_7 d\mathrm{ln}a_t+ \beta_8 \mathrm{dln}p_t+\beta_9 d\mathrm{ln}asp_t+\beta_{10} d\mathrm{ln}pa_t+\beta_{11} d\mathrm{ln}pra+\beta_{12} ddc+\beta_{13} dda+\beta_{14} ddh_{t\pm i}+ \beta_{15} PBR2_{t\pm i}+\varepsilon_t$$

[Table 1]

To determine an adequate specification of the model, diagnostic checks for our functional form were carried out by performing the following specification tests. First, the redundant variable test for inclusion of irrelevant variables was conducted. Two standard test statistics were used, the F-test and the likelihood ratio test. Second, in conjunction with the redundant variable tests, the specification error tests were also used. Specifically, they were performed with two stability tests, the Ramsey's Regression Specification Test (RESET) and the CUSUM test.

---

[13] Logarithms were not taken for the four variables. The proportion of Canola™ varieties, the proportion of Argentina varieties, the proportion of HT/hybrid varieties, and the PBR dummy have values of zero in some years. However, we do take the first difference of these series (except of PBR dummy variable) to be consistent with the rest of the model. When expressed as a first difference the PBR variable was adjusted by creating a seven year reaction curve for PBR centered on 1990 and normalized to sum to 1. Specifically, the values of the PBR2 variable are zero prior to 1987, 1/16 in 1987, 2/16 in 1988, 3/16 in 1989, 1/4 in 1990, 3/16 in 1991, 2/16 in 1992, and 1/16 in 1993. This form allows some anticipation of the legislation and well as a delayed reaction by parts of the private sector.

Given that we have a time series model, testing for serial correlation is very important, since autocorrelated errors is a common finding in time series regression. To test for serial correlation, we use the Breusch-Godfrey Langrange Multiplier (LM) test.[14] The results of the test indicate a first-order serial correlation in the residual AR(1). Hence, the model was specified as an AR(1) process. Finally, the appropriate lag lengths of the cost variables and the dummy variables were determined by the regression that minimizes the AIC.

Based on the diagnostic and model specification tests three model specifications are kept and we rank these models according to the AIC and the adjusted R-squared. The specification of the three regressions differs only with respect to the public applied-research variable. The regression results for these models are reported in the last three columns of Table 2. Model 1 (best fit model) in the fourth column, shows regression results for a 1-year lag in public applied research expenditures. The second-best model on the basis of fit was a 1- and 5-year lag on the public applied research expenditure variable (fifth column of Table 2). Finally, the third-best model on the basis of fit was a 5-year lag on public applied research expenditure variable (last column of Table 2). The magnitudes of the regression coefficients in all the tables are very close. The directions of the effect of exogenous variables on the private research expenditure are in the same direction in all the models except in the case of public expenditure on applied research. Specifically, public expenditure on applied research with a one-year lag positively affects the

---

[14] The LM test is very general, since it can test for first-order, or high-order Auto Regressive Moving Average (ARMA) error.

private research expenditure, while the public research expenditure with 5-year lags negatively affects the private R&D effort.

[Table 2]

The results of the three regressions appear to be robust. Most of the estimated coefficients are individually statistically significant at the 5 per cent level.[15] All the explanatory variables have the expected signs. Moreover, all regressions have an $\overline{R}^2$ between 41 per cent and 51 per cent.

Overall, the econometric results provide empirical evidence to support the theoretical model developed in previous chapters. Specifically, it was found that the effect of public applied research on private applied research expenditure have two directions: in the very short run (1-year lag) causes “crowding in” of private applied research, while in the longer run (5-year lag) it causes “crowding out.” Public applied research expenditure with a 1-year lag has a coefficient of .28 in the first model and .25 in the combined model, implying that, *ceteris paribus*, that a 1 per cent increase in the annual public applied research in one year increases the private research the next year by .28 per cent.[16] While, public applied research expenditure with a lag of 5-year lag has a coefficient ranging from -.14 to -.07. The very short run positive effect of public applied research might be caused by the MII (Matching Initiative Funds) program, where private research investment is matched with public research

---

[15] The significance of the coefficient on the biotechnology variable varies from almost 1% to 20% while the coefficient on the variable of public expenditure on applied research ranges from 2% to 20%. These variables were retained because removing them from these models increase the AIC values and hence reduce the fit of the model significantly.

[16] If the true model is $\ln y = a + b \ln x$ then $\Delta \ln y = b\, \Delta \ln x$, The coefficient b can be interpreted as either as $d\ln y/d\ln x$ which is the elasticity of y w.r.t. x, or equally as $d\Delta\ln y/d\Delta\ln x$, which is the elasticity of the rate of change in y w.r.t. the rate of change in x. Both interpretations are equally valid given the elasticities are equal to the same coefficient, b.

investment. Another possible explanation is that public agencies may spend greater resources just prior to the sale of germplasm to a private company. The private company then spends greater resources for development.

The empirical analysis reveals a positive relationship between public basic research expenditure and applied private research expenditure. The coefficient of public expenditure on basic research is ranging from .20 to .22 in the three models. Because the public basic research expenditure is only 24 per cent of applied private research expenditures, a one dollar increase in public research expenditure will bring about a 90 per cent increase in private applied research expenditure (\$1.00/.24 x .22 = \$0.90). This result provides empirical evidence of the “crowding in” effect of public basic research.

Consistent with a search model of investment, it was found that the total yield index, which shows the current technology level on crop breeding research, negatively affects the level of private investment. The coefficient of the yield index is ranging from –4.18 to –4.51 in the three models. In contrary, the private yield index positively affects the investment level. The coefficient of private yield index is ranging from 2.16 to 2.19. The private yield index variable denotes the current level of private technology. In other words, this will tend to be correlated with the private sector or the firm size. The larger the private market size, the higher the probability of inventing a breakthrough technology, either because the private sector’s ability to take advantage of the public research available is increased or it has the “know-how” and the stock of genes. This in turn results in a larger investment in R&D. This empirical finding is in line with the theoretical result of the model.

Furthermore, it was shown that, the larger the area seeded, the larger the private research investment. The coefficient of the current total acres seeded of rapeseed/canola is ranging from .09 to .17 in the three models. This result denotes that the higher the rate at which the crop is adopted, the larger the size of the market and the larger the private research investment.

Finally, biotechnology and the accompanying increased enforceability of property rights positively affects private applied research investment. The coefficient of biotechnology dummy is ranging from .74 to .89 in the three models. This result is consistent with the theoretical findings that the more complete the IPRs (Intellectual Property Rights), the more intensive a private firm's R&D effort, which in turn results in a bigger investment in research. The differentiated products produced from biotechnology have enhanced the ability of research firms to enforce IPRs and capture the value of their innovation from the marketplace. Hybrid varieties require the purchase of the seed every year to keep the desirable traits, and herbicide-tolerant varieties require the annual purchase of a specialized, patented chemical.

Overall, the econometric results are in accordance with the analytical results derived in this study. The econometric analysis, using data from the canola industry provided empirical evidence to support the analytical framework and the propositions derived in this study. This consistency between the analytical and empirical findings strengthens the validity of the analytical framework developed.

4. Summary and Conclusion

Crop research has undergone a major transformation in North America and many other parts of the world. The introduction of biotechnology and Intellectual

Property Rights (IPR) allows the creation of excludable, non-rival goods. This, in turn, stimulates private investment and changes the structure of the agricultural research industry. The implications of these changes are not fully understood.

The goal of this analysis is to develop a broader understanding of how biotechnology, changes in IPRs and the resulting changes in industry structure have affected the private incentives for agricultural research. To achieve the objective of this study, a three-stage search/imperfect competition model is developed characterized by two research firms developing and selling differentiated products to heterogeneous farmers. Agricultural research is modeled with explicit recognition of the search process, which allows us to recognize research as a stochastic process with sporadic outcomes and to explicitly model the interaction between basic and applied research.

The theoretical results of this study are mainly in form of propositions. Specifically, it was shown that the public role in research is very important in enhancing the productivity of the applied research because basic public research causes a "crowding in" of private applied research. However, applied public research "crowds out" applied private research. It was also shown that the current technology level, in our case yield level, negatively affects private investment. This is similar to the effect that technology level has on the cost of the experimentation. However, when the price of the final product (the price that farmers receive) is increased, a private firm's R&D search is more intense. Moreover, it was concluded that, the greater the product heterogeneity, the higher the price charged with the same amount of R&D. Finally, it was claimed that the increase in the IPR and the firm's market size has a positive effect on the private firm's amount of R&D investment.

The econometric analysis, using data from the canola industry provided empirical evidence to support the analytical framework and the propositions derived in this study. Public basic research caused an increase in private research, as did an increase in the price and area seeded to canola. While recent applied public research expenditure caused and increase in private investment, in the longer run applied public investment tended to crowd out private investment. The overall yield index had a negative effect on investment, while the private yield index had a positive effect on investment. The introduction of biotechnology products that provided effective IPR protection increased the research investment. Overall, the empirical results were very consistent with the theoretical findings.

A number of policy implications can be drawn from the derived propositions. The first point to make is that, for a given distribution of potential outcomes, there is a diminishing return to applied research. This was shown with proposition 3.5, where the higher the current technology level (or research findings), the lower the intensity for the private R&D search, since the probability of inventing a better variety is reduced. Consequently, research into new crops may be more profitable than into well-established ones.

Moreover, basic research is required to maintain the profitability of applied research given that applied research is a search process. Eventually, the current technology level will reach a point where further search is no longer economically viable. Therefore, for applied research to remain profitable in the long run, basic research is required to create new distributions.

Furthermore, it was shown that while, applied public research "crowds out" applied private research, the opposite holds for basic public research. Hence, these propositions suggest that where a private research industry exists, the public sector should shift resources from applied to basic research. This will increase the pace of innovation and research outcomes.

A combination of the "crowd out" proposition and the first proposition, which shows a negative relationship between marginal cost of experimentation and number of research trials, has implications for the type of support given to the research industry. Specifically, government policies that reduce the cost of research –e.g., per unit subsidy increase private investment in R&D. Conversely, public policies that compete with the private sector –e.g., public firms invest in applied research -- would "crowd out" private research investment. Consequently, subsidy may be more effective means to increase applied private R&D investment.

The analysis also reveals an interesting dynamic feedback effect between market size and R&D intensity. A firm with a market size advantage will do more research. By applying more effort to each approach to innovation, the probability of success also rise, which increases the expected value of the yield change and causes an even greater market share. In turn, this allows to crowds firm with smaller market share out of existence, which ultimately results in a concentrated industry with fewer research products. If one goes beyond the scope of our analysis to consider variety *A* and *B* as different crops, then private investment in a large crop will tend to crowd out the research and production of smaller crops. Hence, this finding is in favor of large-scale firms, which supports Schumpeter's hypothesis.

Finally, the increase in appropriability of research benefits via IPRs could have a significant effect on the R&D intensity and welfare implications. An increase in IPRs, while stimulating research investment will leave producers worse off because they will then pay higher prices for varieties. From the social welfare prospective, policy makers have to be aware of the trade-off between overall efficiency and producer welfare. It should be noted, however, that the above analysis assumes that both varieties *A* and *B* will exist in the presence of incomplete IPRs, which may not be the case. If private research firms are unable to reap sufficient returns to pay for the fixed cost involved in research, they may not invest at all which would leave farmers conceivably worse off.

References

Adams, J.D. 1990. "Fundamental Stocks of Knowledge and Productivity Growth." *Journal of Political Science* 98(4): 673-702.

Alston, J.M., and R.J. Venner. 2000. "The Effects of the U.S. Plant Variety Protection Act on Wheat Genetic Improvement." EPTD Discussion Paper No.62.

Alston, J.M., M.C. Marra, P.G. Pardey and T.J. Wyatt. 2000. "Research Returns Redux: a Meta-Analysis of the Returns to Agricultural R&D." EPTD Discussion Paper No.38.

Bergstrom, T., L. Blume, and H. Varian. 1986. "On the Private Provision of Public Goods." *Journal of Political Economy* 29: 25-49.

Brooks, H. 1994. "The Relationship between Science and Technology." *Research Policy* 23: 477-486.

Canola Council of Canada. 1998. "Canola Growers' Manual." http://www.canola-council.org/manual/canolafr.htm. September.

Canola Research Survey. 1999. College of Agriculture, University of Saskatchewan.

CFIA (Canadian Food Inspection Agency). 1998. **"**Canadian Varieties. January 1, 1923 to June 24, 1998." Special Tabulation from the Plant Health and Production Division.

CFIA (Canadian Food Inspection Agency). 2000. http://inspection.gc.ca/english/plaveg/variet/rapecole.shtml. June.

Cohen, W.M. and S. Klepper. 1992. "The Tradeoff between Firm Size and Diversity in the Pursuit of Technological Progress." *Small Business Economics* 4: 1-14.

Dasgupta, P., and P.A. David. 1994. "Toward a New Economics of Science." *Research Policy* 23: 487-521.

David, P.A., B.H. Hall, and A.A. Toole. 1999. "Is Public R&D a Complement or Substitute for Private R&D? A review of the Econometric Evidence." A report prepared for a special issue of *Research Policy*. Cambridge, MA: National Bureau of Economic Research.

Department of Justice, Canada. 2000. http://laws.justice.gc.ca./en/P-14.8/index.html. May.

Diamond, A.M., Jr. 1999. “Does Federal Funding “Crowd In” Private Funding of Science?” *Contemporary Economic Policy* 17: 423-431.

Enriquez, J. 1998. “Genomics and the World’s Economy.” *Science* 281 : 925-6.

Epstein, B. 1960. “Elements of the Theory of Extreme Values.” *Technometrics* 2: 27-41.

Evenson, R.E., and Y. Kislev. 1976. “A Stochastic Model of Applied Research.” *Journal of Political Economy* 84: 265-281.

Forhan, M. 1993. "Canola Breeding Goes Private." *Canola Guide.* Pp. 28 – 31.

Fulton, M., and D. Giannakas. 2000. “The Effects of Biotechnology on Concentration and Structure in the Agricultural Inputs Industry.” A discussion paper prepared for Agriculture and Agri-Food Canada.

Fulton, M.E. 1997. “The Economics of Intellectual Property Rights: Discussion.” *American Journal of Agricultural Economics* 79: 1592-1594.

Fulton, M.E., and L. Keyowski. 1999. “The Impact of Technological Innovation on Producer Returns: The Case of Transgenic Canola.” Presented at the NE-165 conference, *Transitions in Agbiotech: Economics of Strategy and Policy*. Washington, DC, June 24-25.

Gray, R. and S. Malla. 2000. “The Economics of CWRS Wheat Research in Western Canada 1961-1998.” A Report Prepared for Agriculture Development Fund. Regina.

Gray, R., S. Malla, and S. Ferguson. 2000. “Agricultural Research Policy in Canada: Past Experience and Future Directions.” A report prepared for Saskatchewan Agriculture and Food. CSALE, University of Saskatchewan: Saskatoon.

Griliches, Z. 1986. “Productivity, R&D, and Basic Research at the Firm Level in the 1970’s.” *The American Economic Review* 76(1): 141-154.

Gumbel, E.J. 1958. “Statistics of Extremes.” New York: Columbia University Press.

Huffman, W.E. and R.E. Evenson. 1993. “Science for Agriculture: A Long-Term Perspective.” Ames: Iowa State University Press.

ICAR (Inventory of Canadian Agri-Food Research). 1998. Special Tabulation upon Request.

ICAR (Inventory of Canadian Agri-Food Research). 2000. Special Tabulation upon Request.

ISI (Institute for Scientific Investigation). 1997. Citations Database, Special Tabulation of Academic Publications Based on Key Word Search for Canola. November, 1997.

Johnson, D.K.N., and R.E. Evenson. 1999. "R&D Spillovers to Agriculture: Measurement and Application." *Contemporary Economic Policy* 17: 432-456.

Jorgenson, D.W., and F.M. Gollop. 1992. "Productivity Growth in U.S. Agriculture: A Postwar Perspective." *American Journal of Agricultural Economics* 74: 745-750.

Khanna, J, and T. Sandler. 1996. "UK Donations Versus Government Grants: Endogeneity and Crowding-In." Presented at American Economic Association meeting, San Francisco, Cal., January 1996.

Khanna, J., J. Posnett, and T. Sandler. 1995. "Charity Donations in the UK: New Evidence Based on Panel Data." *Journal of Political Economy* 56: 257-272.

Lesser, W. 1998. "Intellectual Property Rights and Concentration in Agricultural Biotechnology." *AgBioForum* 1: 56-61.

Lindner, R. 1999. "Prospects for Public Plant Breeding in a Small Country." Presented at the ICABR Conference, "The Shape of the Coming Agricultural Biotechnology Transformation: Strategic Investment and Policy Approaches from an Economic Perspective." University of Rome, "Tor Vergata," Rome and Ravello, June 17-19.

Malla, S. 1996. *The Distribution of the Economic and Health Benefits from Canola Research.* M.Sc.Thesis, University of Saskatchewan: Saskatoon.

Malla, S., and R. Gray. 1999. "The Effectiviness of Research Funding in the Canola Industry." A Report Prepared for Agriculture Development Fund. Regina.

Malla, S., R. Gray and P. Phillips. 1998. "The Evaluation of Canola Research: An Example of Success." A Report Prepared for Agriculture Development Fund. Regina.

Manitoba Crop Insurance Corporation. 2000. *Variety Survey*. http://www.mmpp.com/index.html. June.

Moschini, G., and H. Lapan. 1997. "Intellectual Property Rights and the Welfare Effects of Agricultural R&D." *American Journal of Agricultural Economics* 79: 1229-1242.

Nagy, J.G. and W.H. Furtan. 1978. “Economic Costs and Returns from Crop Development Research: The Case of Rapeseed Breeding in Canada.” *Canadian Journal of Agricultural Economics* 26: 1-14.

Nagy, J.G., and W.H. Furtan. 1977. “The Socio-Economic Costs and Returns from Rapeseed Breeding in Canada.” Department of Agricultural Economics. Saskatoon: University of Saskatchewan.

Nelson, R.R. 1970. “Information and Consumer Behavior.” *Journal of Political Economy* 78: 311-329.

Pannel, D.J. 1999. “On the Balance between Strategic-Basic and Applied Agricultural Research.” *The Australian Journal of Agricultural and Resource Economics* 41(1): 91-113.

Pavitt, K. 1991. “What Makes Basic Research Economically Useful?” *Research Policy* 20: 109-119.

Phillips, P. 1997. Manual Search of ISI Citations Index, July.

Prairie Pools Inc. 1992-1997. “Prairie Grain Variety Survey.” Various Issues.

Rausser, G. 1999. “Public/Private Alliances.” *AgBioForum* 2(1): 5-10.

Roberts, R.D. 1984. “A Positive Model of Private Charity and Public Transfers.” *Journal of Political Economy* 92:136-148.

Romer, P. 1990. “Endogenous Technological Change.” *Journal of Political Economy* 98(2): S71-S102.

Rosenberg, N. 1990. “Why Do Firms Do Basic Research (With Their Own Money)?” *Research Policy* 19(2): 165-174.

Rosenberg, N. 1991. “S&T Interfaces.” *Science and Policy* 18(6): 335-346.

Saskatchewan Agriculture and Food. *Varieties of Grains Crops in Saskatchewan.* Various Issues.

Saskatchewan Agriculture and Food. 1999. *Agricultural Statistics*.

Saskatchewan Agriculture and Food. 1999. *Market Trend*. Various Issues.

Schumpeter, J.A. 1934. *The Theory of Economic Development.* Cambridge: Harvard University Press.

Schumpeter, J.A. 1942. *Capitalism, Socialism, and Democracy.* New York: Harper.

Solow, R. 1957. “Technical Change and the Aggregate Production Function.” *Review of Economics and Statistics* 39: 312-320.

Statistics Canada. 2000. *Direct Cansim Time Series: CPI and All Goods for Canada*. June 27, 2000.

Statistics Canada. 2000. *Direct Cansim Time Series: Canola – Rapeseed/Production, Metric Tonnes, Canola – Canada.* July 4, 2000.

Steinberg, R. 1993. “Does Government Spending Crowd Out Donations? Interpreting the Evidence.” In *The Nonprofit Sector in the Mixed Economy*, Avner Ben-Ner and Benedetto Gui, eds., Ann Arbor: University of Michigan Press, 99-125.

Stigler, G.J. 1961. “The Economics of Information.” *Journal of Political Economy* 69: 213-225.

Sunding, D., and D. Zilberman. 2000. “The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector.” In the *Handbook of Agricultural Economics*. (http://are.berkeley.edu/˜zilber/selected%20papers.html).

Thirtle, C., P. Bottemley, P. Palladino, D. Schimmelpfennig, and R. Townsend. 1998. “The Rise and Fall of Public Sector Plant Breeding in the United Kingdom: A Casual Chain Model of Basic and Applied Research and Diffusion.” *Agricultural Economics* 19: 127-143.

Warr, P.G. 1982. “Pareto Optimal Redistribution and Private Charity.” *Journal of Public Economics* 19: 131-138.

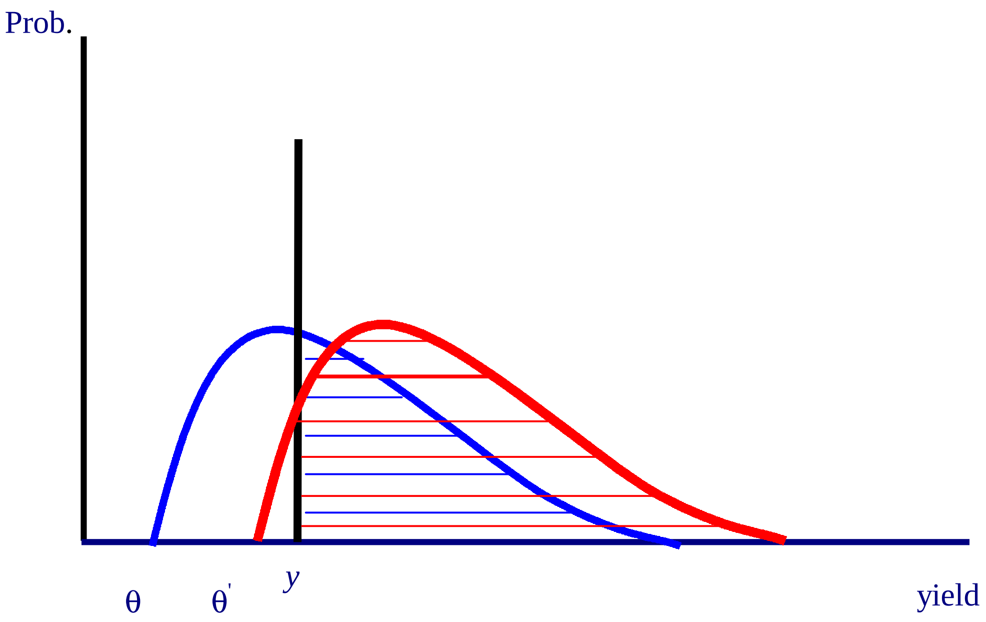

Figure 1: The Effect of a Change in θ on the Yield Distribution

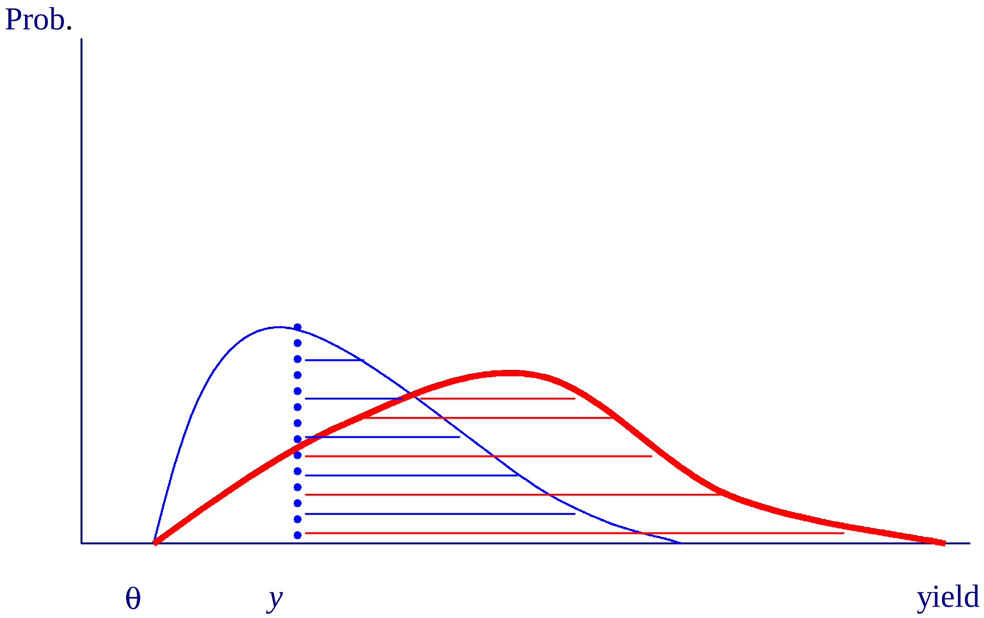

Figure 2: The Effect of a Change in λ on the Yield Distribution

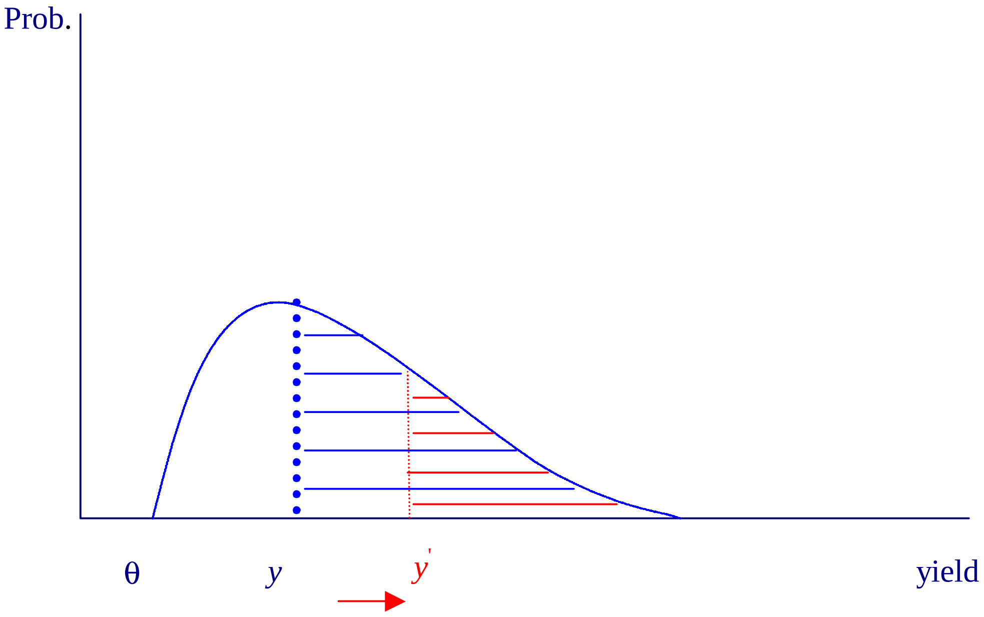

Figure 3: The Effect of a Change in *y* on the Yield Distribution.

Table 1: Description of the variables used in the econometric analysis.

Acro-nym*	**Varables****	**Source of Prior Belief**	**Expected Sign**
Dependent variable: dlnprc$_t$ (private applied research expenditure for year t)			
t	time trend		
$d\ln pca_{t-i}$	public applied research expenditure for year *t* minus *i* years of lag,	*Proposition 3.5*: Crowding-out effect	-
$d\ln pcb_{t-i}$	public basic research expenditure for a year *t* minus *i* years of lag,	*Proposition 3.3*: Crowding-in effect	+
$d\ln ti_t$	total yield index for year *t*	*Proposition 3.4*: The higher the current yield level, the less the applied R&D investment	-
$d\ln pri_t$	private yield index for year *t*	*Proposition 5.1*: The larger the market size of the firm, the larger the applied R&D investment	+
$d\ln pi_t$	public yield index for year *t*	*Proposition 3.5*: Crowd-out effect.	+
$d\ln a_t$	area seeded of canola crop for year *t*	*Proposition 5.1*: The larger market size, the larger the applied R&D investment	+
$d\ln p_t$	farm-gate price of canola for year *t*	*Proposition 3.2*: The higher the product price, the larger the applied R&D investment	+
$d\ln asp_t$	area seeded to canola times the farm-gate price of canola for year *t*	Interaction of effects in *Propositions 5.1 and 3.2*	+
$d\ln pa_t$	area seeded to public canola varieties for year *t*	*Proposition 3.5*: Crowding-out effect.	-
$d\ln pra_t$	area seeded by private canola varieties for year *t*	*Proposition 5.1*: The larger the market size, the larger the applied R&D investment	+
ddc_t	proportion of the total canola area that is seeded to Canola™ varieties in year *t*	Exogenous quality adjustment (Malla and 1999)	+
dda_t	proportion of the total canola area seeded to Argentina (*b. napus*) varieties in year *t*	Yield index adjustment (Malla and Gray 1999)	+
$ddh_{t \pm i}$	proportion of the total canola area seeded to	*Proposition 4.1*: The more complete the IPR, the larger	+

	herbicide-tolerant and hybrids varieties in year *t* minus/plus *i* years of lag/lead	the applied R&D investment.	
$dPBR2_{t \pm i}$	Plant Breeders' Rights dummy variable minus/plus *i* years of lag/lead	*Proposition 4.1*: The more complete the IPR, the larger the applied R&D investment	+

---

[*] All variables are in the first difference of logarithms,(denoted as *d*ln in the acronym) except the variables current proportion of area seeded to canola™ varieties; current proportion of area seeded to Argentine (*b.napus*) varieties; and lead/lag of Plant Breeders' Rights Dummy. For these variables, a simple first difference is used (denoted as dd in the acronym).

**Time series data were calculated based on the following sources:

$d\ln prc_t$, $d\ln pca_{t-i}$, $d\ln pcb_{t-i}$: Canola Research Survey (1999); Nagy and Furtan (1977); ISI (1997), Phillips (1997); ICAR (1998, 2000); and CFIA *special tabulation provided upon request* (1998),

$d\ln ti_t$, $d\ln pri_t$, $d\ln pi_t$: Saskatchewan Agriculture and Food, *Varieties of Grain Crops in Saskatchewan* (various issues); Nagy and Furtan (1978); Prairie Pools Inc. *Prairie Pools Variety Survey* (various issues); and the authors' estimates based on the Manitoba Crop Insurance Corporation Variety Survey (wepage, access June 2000),

$d\ln a_t$, $d\ln pa_t$, $d\ln pra_t$: Nagy and Furtan (1978); Prairie Pools Inc., *Prairie Pools Variety Survey* (various issues); CFIA *special tabulation provided upon request* (1998); and the authors' estimates based on the Manitoba Crop Insurance Corporation Variety Survey (wepage, access June 2000),

$d\ln p_t$: Saskatchewan Agriculture and Food, *Market Trend* (various issues); and Saskatchewan Agriculture and Food, *Agricultural Statistics* (1999); and Statistics Canada, *Direct CANSIM Time Series: CPI and All Goods for Canada* (wepage, access June 2000),

ddc_t, dda_t, : Saskatchewan Agriculture and Food, *Varieties of Grain Crops in Saskatchewan* (various issues); Prairie Pools Inc., *Prairie Pools Variety Survey* (various issues); Nagy and Furtan (1978); and the authors' estimates based on the Manitoba Crop Insurance Corporation Variety Survey,

$ddh_{t \pm i}$: Saskatchewan Agriculture and Food, *Varieties of Grain Crops in Saskatchewan* (various issues); Prairie Pools Inc. *Prairie Pools Variety Survey* (various issues); Nagy and Furtan (1978); the authors' estimates based on the Manitoba Crop Insurance Corporation Variety Survey; and CFIA (wepage, access June 2000),

$dPBR2_{t \pm i}$: authors' estimates based on the fact that PBR came into force August 1, 1990 (Department of Justice, wepage, access May 2000).

Table 2: The Final Regression Results

Variable[*]	Acro-nym	Expect -ed Sign	Model 1 Coeff. (t- value)	Model 2 Coeff. (t- value)	Model 3 Coeff. (t- value)
Private applied research expenditure (dependant variable)	$d\ln prc_t$				
Constant	Constant		-.109 (-2.54)	-.083 (-2.04)	.-.012 (-.28)
Lagged public applied research expenditure lag –1	$d\ln pca_{t-1}$	-	.277 (2.55)	.247 (3.45)	na
Lagged public applied research expenditure lag –5	$d\ln pca_{t-5}$	-	na	-.072 (1.35)	-.143 (1.44)
Lagged public basic research expenditure lag –5	$d\ln pcb_{t-5}$	+	.215 (3.55)	.20 (4.35)	.213 (3.20)
Current total yield index	$d\ln ti_t$	-	-4.19 (4.79)	-4.18 (7.12)	-4.51 (-4.85)
Current private yield index	$d\ln pri_t$	+	2.19 (3.41)	2.18 (7.17)	2.16 (3.10)
Current public yield index	$d\ln pi_t$	+	na	na	na
Current total area seeded of rapeseed/canola	$d\ln a_t$	+	.0858 (2.12)	.108 (2.30)	.169 (3.75)
Current farm gate price of rapeseed/canola	$d\ln p_t$	+	na	na	na
Current area seeded times the price of rapeseed/canola	$d\ln asp_t$	+	na	na	na
Current area seeded to public rapeseed/canola varieties	$d\ln pa_t$	-	na	na	na
Current area seeded to private rapeseed/canola varieties	$d\ln pra_t$	+	na	na	na
Current proportion of area seeded to Canola™ varieties	ddc_t	+	na	na	na
Current proportion of area seeded to Argentine (*b. napus*) varieties	dda_t	-	na	na	na
Proportion of area seeded to HT and hybrid varieties lead +3	ddh_{t+3}	+	.884 (1.89)	.847 (4.70)	.74 (1.47)
Lead/lag of Plant Breeders' Rights Dummy	$dPBR2_{t\pm i}$	+	na	na	na
Trend	trend		.010 (5.55)	.010 (-6.13)	.007 (3.94)
AR(1)			-.69 (-433)	-.71 (-6.13)	-.72 (4.73)
Akaike info criterion			-1.76	-1.72	-1.58
R^2			0.645	.66	.57
$\overline{R^2}$			.51	.50	.41

Source: Author's Regression Estimates

[*] To address unit root problems, all variables are calculated in the first difference of logarithms,(denoted as *d*ln in the acronym) except the variables current proportion of area seeded to canola™ varieties; current proportion of area seeded to Argentine (*b.napus*) varieties; and lead/lag of Plant Breeders' Rights Dummy. For these variables, a simple first difference is used (denoted as dd in the acronym).