An Empirical Analysis of Public and Private Spillovers within the Canola Biotech Industry

Richard Gray, Stavroula Malla and Kien Tran
(no senior authorship assigned)

University of Saskatchewan, SK, Canada

Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting,

Montreal, Canada, July 27-30, 2003

An Empirical Analysis of Public and Private Spillovers within the Canola Biotech Industry

<u>Abstract</u>

The study uses firm-specific data in the biotech canola industry to empirically examine research spillovers among public and private firms at the level of research output, research sales revenue, and research social revenue. The non-pecuniary spillovers that are examined include basic research, human capital/ knowledge (as measured through other-firm expenditures) and genetics (as measured through yields of other-firms). The results provide strong empirical evidence of several research spillovers in the biotech crop research industry such as: basic and applied public research creates a positive spillover for private firms at all levels; applied expenditure within-group reduces other-firm revenue while between-group expenditure increases revenue; genetic spillovers within-group have a positive impact on yield but tend to have a negative impact on firm revenue.

Key words: non-pecuniary research spillovers, pecuniary research spillovers, basic research, applied research, public research expenditures, private research expenditures, biotechnology, canola industry.

The Distribution of Benefits and Spillovers within an Ag-Biotech Industry

I. Introduction

Research spillovers have played a major role in the formation of crop research policy. During most of the 20th century, the public good aspect of research was recognized as a spillover, with the result that most crop research was undertaken by public institutions and the products of the research were held in the public domain (Huffman and Evenson 1993). The recent introduction of modern biotechnology and improved Intellectual Property Rights (IPRs) has helped address these spillovers and has resulted in substantial private investment in agricultural research. The inherent non-rival nature of research products, along with *freedom to operate* costs, has led to rapid consolidation and a concentrated agricultural research industry (e.g., Lindner 1999). Recent studies show that while IPRs create incentives to invest they also create market power and efficiency losses (e.g., Moschini and Lapan 1997). Despite the extent of the changes, there are few empirical studies of spillovers within the modern biotech industry.

Change has been particularly evident in the canola research industry. After three decades of public leadership, the canola industry has become dominated by large private firms employing biotechnology to produce tailored products for the marketplace. Since 1985, the private sector has directed about 60% of the total investment in technology and variety development, which yielded control of approximately 85% of the resulting varieties and more than 90% of the new technologies. By the year 2000, 75% of the canola acreage was planted to varieties that required farmers to make annual purchases to retain access to the technology (Gray et al. 2001). Despite the importance of these changes in crop research, a lack of firm-specific data has hampered the analysis and understanding of the biotech industry.

In this paper we empirically explore the role of research spillovers. The study uses firm-specific data in the canola industry to empirically examine a number of research spillovers among public and private firms. The spillovers are examined at the level research output, research sales revenue, and research social revenue. The non-pecuniary spillovers that are examined include the spillovers from basic research, the spillovers of human capital and knowledge (as measured through other-firm expenditures), and genetic spillovers (as measured through yields of seed from other-firms). The pecuniary spillovers from market impacts are examined through the private and social revenue functions.

The remainder of the paper is organized into four sections. Section II outlines the relevant literature and the theoretical framework used for this analysis. Section III provides a brief description of the data used in the econometric analysis. The empirical model and the results are reported in Section IV. Section V contains the concluding comments of the paper.

II. Research Spillovers

Literature Review

Research spillovers are a very important determinant of economic productivity and patenting (e.g., Griliches 1992, Jaffe 1986, Adams 1990, Adams and Jaffe 1996, Adams 1999). Research spillovers, or externalities that arise from the public-good aspects of knowledge, are at the heart of the economics of research and have assumed a central role in endogenous growth theory, both in terms of physical capital (e.g., Romer 1986, 1990, Aghion and Howitt 1992) and human capital (e.g., Lucas 1988). Spillovers also have important implications for behavior/performance (e.g., Adams 2000, Cohen and Levinthal 1989) and market structure/industrial organization of the firm (e.g., Spence 1984, Dasgupta and Stiglitz 1980, Levis and Reiss 1984, 1988). Acs et al. (1994) examined the research spillovers from the prospective of the recipient firm and concluded that “small firms are the recipients of R&D spillovers from knowledge generated in the R&D spillovers centers of their large counterparts and in universities” (p. 336).

The seminal work of Evenson and Kislev (1976) introduced the notion of basic research spillover. Specifically, they developed a theoretical model of innovation as a search process, illustrating that the outputs of basic research (i.e., scientific knowledge) can improve the productivity of applied research. The work of Evenson and Kislev (1976) has been verified by a number of later studies (e.g., Lee 1982, Lee 1985, Kortum 1997).

A significant body of economic research has addressed the crowding effects of public research investment on private research investment. Several economists have developed theoretical models that show publicly funded research compete for scarce resources and could therefore "crowd out" privately funded research (e.g., Roberts 1984, Bergstrom et al. 1986, David and Hall, 2000). Other economists who have considered charitable donations (e.g., Khanna et al., 1995, Khanna and Sandler 1996) show that public expenditure could have the opposite effect and cause a "crowding in" of private research expenditure. There are many studies that examine crowding effects empirically. David, Hall and Toole (1999) provided a recent survey of the available empirical evidence and found that the results were inconclusive regarding the direction and the magnitude of the relationship between public and private research expenditure. Diamond (1999) and Robson (1993) empirically examined the crowding effects of basic research.

The effects of spillovers on agricultural productivity have also attracted significant attention in the literature (e.g., Johnson and Evenson 1999, Griliches 1979, 1980, Evenson 1989, Huffman and Evenson 1993, White, He and Fletcher 2003), while a number of studies examined the cross-state spillovers from agricultural research (e.g., Evenson 1989, Yee and Huffman 2001). Finally, Pardey et al. (1996) examined the genetic research spillovers through pedigree attribution among different breeding programs, which is applicable when crop pedigrees are known (Heisey and Morris 2002).

Model

We model the canola industry as public and private research firms that expend resources to develop varieties with higher yields and herbicide tolerance, which are sold to farmers. The framework distinguishes between basic research, which uses capital and other-expenditure for the development of research platforms for innovation, and applied research, which uses the research platforms, existing varieties, and human capital to produce new higher yielding crop varieties, with or without herbicide tolerance. The varieties sold to farmers provide a social return to innovation equal to the increase in yield plus the per-acre herbicide savings multiplied by area sown.

The model considers several possible non-pecuniary spillovers. Some of the expenditure on basic research (undertaken by public firms) will benefit applied research. The development of human capital can, through communication or transfer of people, increase the productivity of applied research of other-firms. A genetic improvement of one firm through either mimicking the innovation or the direct transfer of germplasm can increase the research productivity of other-firms. Finally, there is a non-pecuniary transfer of benefits from the research firms to the downstream users of the technology if the IPRs are not effective.

The pecuniary externalities for applied research can come through either the market price of research inputs or the market price of the research output. If human capital is limited, a greater expenditure by one firm can increase the cost of research resources for other-firms. On the output side, increased research output by one firm can reduce the price of new varieties, thereby reducing the profitability of other-firms.

In the econometric model to follow, we measure firm-to-firm spillovers at three different levels: 1) at the level of each firms research/yield function; 2) at the level of sales revenue of each firm; and 3) at the level of social benefits embodied in each firm's varieties. In the estimation we make a further distinction between public and private research enterprises. This multi-level approach allows us to separate some pecuniary spillovers from non- pecuniary spillover effects, and to illuminate a number of distributional effects.

The average yield of varieties of firm i in period t is described by the function:

$$Y_{it} = f(Y_{i,t-1}, AR_{i,t-k} \cdot \phi_t(OA_{i,t-k}, BR_{t-k}), OAR_{i,t-r}, OY_{i,t-m}, BR_{t-l}), \qquad (1)$$

which is an increasing function of the previous period's yield, $Y_{i.t-1}$, lagged quality-adjusted own-research expenditures, $AR_{i.t-k}$, and through non-pecuniary spillovers is an increasing function of the lagged expenditure of other-firms, $OAR_{i.t-r}$, the lagged yield of other-firms, $OY_{i.t-m,}$ and lagged basic research expenditures, $BR_{.t-m}$. Equation 1 is a physical relationship that can be estimated directly from research data.

The second level of relationship estimates the determinates of research firm revenues. The revenue generated in period t from varieties at firm i is the sum of sales revenue and technical use fees. The revenue generated will be a function of those variables that affect variety yields, as well as the variables that measure IPRs and the pecuniary effects of competition. Specifically,

$$R_{i,t} = g(BR_{t-l}, AR_{i,t-k}, OAR_{i,t-r}, OY_{i,t-g}, PBR_t, TUREV_{i,t}, R_{i,t-1}). \qquad (2)$$

In this case sales revenue, $R_{i,t}$, is an increasing function of lagged basic research, BR_{t-l}, lagged applied research, $AR_{i,t-k}$, plant breeders rights, PBR_t , technical use revenue

$TUREV_{i,t}$, and sales revenue from the previous period. The spillovers from other-firms' applied research expenditure, $AR_{i,t-k}$, and yield of other-firms' varieties, $OY_{i,t-g}$, could be positive (negative) if the non-pecuniary effects are greater (less) than the pecuniary spillovers.

The third level of relationship estimates the production of social revenue associated with the varieties sold by each firm. In this case, the annual social benefit is approximated as the increase in economic surplus generated from the yields since 1960 plus the herbicide savings rent. The economic surplus attributed to yield is estimated as the yield increase on the area sown to the firm's varieties multiplied by prevailing prices. The social revenue for firm i in period t can be described as:

$$SR_{i,t} = k(BR_{t-l}, AR_{i,t-k}, OAR_{i,t-r}, PBR_t, SR_{i,t-1}) . \quad (3)$$

The social revenue, $SR_{i,t}$, is expected to be an increasing function of lagged basic research, BR_{t-l}, an increasing function of the firm's lagged applied research, $AR_{i,t-k}$, an increasing function the plant breeders rights, PBR_t, and an increasing function of the previous period social revenue, $SR_{i,t-1}$. The effect of other-firms' lagged applied research, $OAR_{i,t-r}$, will be negative (positive) if the crowding impacts of other-research are greater (less) than the knowledge spillover effects.

III. Data Description

This subsection describes the source and the calculations used to construct each of the variables required for the econometric analysis.

Research Expenditure on Canola

Developing the time series for public and private research expenditures from 1960 to 1999 required the combination of several sources of data and several calculations because no single source spanned the time period and some sources were more accurate than others for some types of expenditures. For all of the calculations, the total research expenditure per year was calculated by multiplying the total (professional and technical) person-years employed in research each year by the 1999 total research costs per person (Canola Research Survey 1999). To avoid the problem of double counting, the research expenditure is calculated at the final recipient level. Data on canola research person-years were obtained from five sources: Canola Research Survey (1999); Nagy and Furtan (1977, 1978); ISI (Institute for Scientific Investigation) (1997); Phillips (1997); and ICAR (Inventory of Canadian Agri-Food Research) (1998 and 2000).

Canadian universities' total person-years were based on an ISI special tabulation of academic publications (from 1981 to 1996) and ICAR data (from 1977 to 1980) (for the 1978 value the average of 1977 and 1979 was used). Prior to 1976, when ICAR data was not available, Nagy and Furtan (1977, 1978) was used, with some adjustments. Comparing the Nagy and Furtan estimates of total professional person-years at Canadian universities to the ICAR estimates of total professional years, the former were underestimated by 62 percent. Hence, the Nagy and Furtan estimates were adjusted by multiplying by 2.64. The data were updated by applying the average value of the last three available years to the 1997, 1998, and 1999 values.

Non-Canadian universities' total person-years were based on an ISI special tabulation of academic publications (from 1981 to 1997), and on Phillips (1997) (from 1960 to 1980). Comparing the ISI special tabulation of non-Canadian academic total person-years to the Phillips' estimate (for the overlapping years 1981 and 1982), the former was underestimated by 23 percent. Hence, Phillips' estimates were adjusted by multiplying by 1.3. The non-Canadian universities' total person-years figure was updated following the same methodology as the Canadian universities' total person-years.

AAFC total person-years were based on ICAR data (1998 and 2000) from 1977 to 1999 (for the 1978 value the average of 1977 and 1979 was used), and Nagy and Furtan (1977, 1978) (from 1960 to 1976). Comparing the Nagy and Furtan estimate of professional person-years to the ICAR estimate of total professional years, the former represented only 30 percent of the total person-years. Hence, the Nagy and Furtan (1977, 1978) estimates were adjusted accordingly.

The estimation of public expenditures on basic and applied research was based on the ICAR database and the public research expenditure (as described above). Upon request, ICAR personally provided us with project descriptions and subcategories of research in the 556 projects undertaken over the years on canola research. With the help of experts in crop science, the research in each project was divided into basic and applied research, and then aggregated to calculate the percentage of basic and applied research in each year. This percentage for the ICAR-listed projects was applied to all reported public research expenditures on canola, which resulted in a time series of public expenditures on basic and on applied research.

The estimation of the private companies' professional years was based on the Canola Research Survey (1999), a detailed firm-level study undertaken by Peter Phillips and others at the University of Saskatchewan.

<u>Yield index</u>

The annual yield index by firm was created from an average of the yield index for the firm's varieties grown each year, weighted by the seeded acreage.[1] The relative yields of different canola varieties were obtained from various issues of Saskatchewan Agriculture and Food, *Varieties of Grain Crops in Saskatchewan* (various issues), which are based on annual side-by-side variety yield trails at several locations in the province.[2] The data on the percentage of acreage sown to each canola variety were obtained from four sources: Nagy and Furtan (1978); various issues of Prairie Pools Inc., *Prairies Grain Variety Survey* (1977-1992); and the authors' estimates based on Manitoba Crop Insurance Corporation, *Variety Survey* (December 2002) and Alberta Crop Insurance Corporation, *Variety Survey* (December 2002).[3]

<u>Variety Classification</u>

Information on the types of rapeseed/canola varieties (Polish/Argentine), the breeders, the year of introduction, the variety's production system, (open pollinated, synthetic, hybrids), the variety's reproduction system (conventional versus herbicide-tolerant e.g., Round up Ready®, Clearfield®, Liberty®) which allowed us to classify each canola

---

[1] The relative yield index of different canola varieties was converted to the same variety base (Torch) (1976=100). The yield index for each variety is obtained from the last reported value because it is thought to be a more accurate estimate of the actual yield performance.

[2] Unfortunately, the whole series was not available from other provinces, so the data from Saskatchewan is used as a national proxy, which may be a reasonable approximation given that Saskatchewan is located in the center of the canola-growing region.

[3] The proportion of acres grown in Manitoba and Alberta was used to create the weighted average after 1990, which applied to the total canola acreage in the prairies (Statistics Canada, *Direct CANSIM* Time Series: Prairie Provinces; Seeded Area; Canola (Rapeseed), December 2002).

variety, was collected from the following sources: Saskatchewan Agriculture and Food, *Varieties of Grain Crops in Saskatchewan* (various issues); CFIA (Canadian Food Inspection Agency) (1998, 2002, 2003); Alberta Agriculture and Food, *2003 Agronomic Performance Data for all Crops and Regions* (2002, 2003); Manitoba Agriculture and Food, *2003 Variety Guide for Oilseeds and Special Crops* (2003); Paterson and Sons Limited Grain Buyer, *Polish and Argentine Canola Varieties* (2003); Alberta Seed Industry, *New in 2001: Canola, Flax, and Mustard Varieties – 2001* (2003); and Canola Council of Canada, *Argentine Varieties and Polish Varieties* (2002, 2003).

Argentine and Biotechnology Variables

(herbicide-tolerant (HT); hybrid (HYB); plant breeders' rights (PBR))

Two types of rapeseed/canola varieties are grown in Canada: Argentine species (*Brassica napus L.*) and Polish species (*Brassica rapa L.*). These two species of rapeseed/canola have different yield and other agronomic characteristics. An Argentine variable representing the proportion of total area seeded to Argentine varieties was calculated for each firm each year (for details on the sources of varieties' classification see above).

To capture the effect of cultivating herbicide-tolerant (HT) and synthetic/hybrid canola varieties (HYB), two variables were created that show the proportion of the total canola area seeded to varieties that are HT and the proportion of the total canola area that are hybrids. The HT and HYB variables take a value between 0 and 1 (for details on the sources of varieties' classification see above).

The effect of Plant Breeders' Rights (PBR) was incorporated by creating a PBR dummy variable. This variable takes the value of 0 before the BPR Act came into force on August 1, 1990 (Department of Justice 2000), and 1 thereafter.

Price and Revenue Variables

(Private Revenue; Technical Use Agreement (TUA) Revenue; Social Revenue)

The farm gate price of canola/rapeseed in Canada was based on Saskatchewan Agriculture and Food, *Agricultural Statistics 2002*. The farm gate price of canola as well as all the revenue variables were expressed as 2001 Canadian dollars per tonne as deflated by the consumer price index. The data for the consumer price index (CPI) were obtained from Statistics Canada*, Direct CANSIM Time Series: CPI and All Goods for Canada* (January 2003).

The annual revenue by firm is the product of the price charged for each variety and the seeded acreage for each variety (for details on the sources of the area data see "Yield Index"). The price data of canola varieties was obtained from various issues of Canola Council of Canada*, Economic Analysis: CPC Annual Reports* (2002) [4]; SeCan (2002); Saskatchewan Agriculture and Food (2002); and authors' estimates based on the above sources.[5]

The Technical Use Agreement (TUA) fees or their equivalent annual rents equivalent were obtained from various issues of Canola Council of Canada*, Economic Analysis: CPC Annual Reports* (2002) and authors' estimates.[6] The TUA revenue was calculated by multiplying the TUA fees/equivalent and the area seeded per each canola variety per year.

Finally, the estimation of the annual social revenue produced by each firm each year was based on the notion that social value can be broken down to yield-induced increase and the herbicide cost savings reflected in the TUA fees. The estimated value of the yield increase from firm i in year t begins with the calculation of the commercial value of the product grown to their varieties, which is the product of the area $A_{it,}$ the price of canola, P_t, and the average commercial yield in year t, Yt. The social value of the yield increase attributed to firm i is this commercial value multiplied by the proportional yield increase over the 1960 yield, or $(Y_{it}- Y_0)/Y_{0.}$ The total social revenue is herbicide TUA revenues plus the value of the yield increase or:

---

[4] The Canola Council data set was reduced by the average seed treatment costs for canola. The determination of the average seed treatment price for canola from 1991 to 2001 was based on David Blais (2003) (personal communication) and Jim Rogers (2003) (personal communication).

[5] Gaps in the data were filled in using the calculated annual average price of the canola seed per type per year or/and forecasting the seed price using the existing data as the underlying trend.

[6] Monsanto charges a $15 TUA fee per-acre for all Roundup-Ready canola grown to extract value from producers. Two other companies that promote the development of herbicide-tolerant canola varieties, BASF (Clearfield canola sprayed with Odyssey herbicide) and Aventis (Liberty-Link canola sprayed with Liberty Herbicide), hold patents on the herbicides and can set the price wherever they want. The prices of Liberty and Odyssey herbicides are quite high when compared with Roundup. The calculated TUA equivalents per-acre for these varieties are based upon the notion that if BASF and Aventis faced a competitive market for their herbicides they could be expected to sell their chemical for the price of Roundup, the excess revenue being rents. The herbicide costs used for this calculation was Roundup $8.15/acre, Odyssey $20.38/acre, and Liberty $18.50/acre.

$$SR_{it} = RTUA_{it} + P_t * Y_t \left(\frac{Y_{it} - Y_0}{Y_{it}} \right) A_{it} \tag{4}$$

where:

SR_{it} is the social revenue of firm *i* in year *t*

$RTUA_{it}$ is the TUA (technical use agreement) revenue of firm *i* in year *t*

P_t is the farm gate price of canola in year *t*

Y_t is the annual average weighted yield index of the Argentine canola varieties in year *t*

Y_{it} is the weighted yield index of the Argentine canola varieties of firm *i* in year *t*

Y_0 is the annual average weighted yield index of the Argentine canola varieties in year *t*=0 (1960)

A_{it} is the area seeded of each canola variety of firm *i* in year *t*

IV. Econometric Analysis

Econometric Models Specification

We consider three different models for the analysis of research spillovers. Since our primary interests are to examine the effect of both basic and applied research spillovers from public firms to private firms, and not *within* the private firms and/or the public firms themselves, we divide the firms in to two groups: private firms and public firms. In the first model, we consider the following specification:

Model 1:

$$\begin{aligned} Y_{i,t}^{PV} &= \beta_{0i} + \beta_1 BR_{t-l} + \beta_2 AR_{i,t-k}^{PV} + \beta_3 OAR_{i,t-r}^{PV} + \beta_4 AR_{t-m}^{PUB} + \beta_5 OY_{i,t-h}^{PV} + \\ &\quad \beta_6 Y_{t-g}^{PUB} + \gamma_i Y_{i,t-1}^{PV} + u_{i,t}, \qquad i = 1,\ldots,5 \end{aligned} \tag{5}$$

$$\begin{aligned} Y_{j,t}^{PUB} &= \delta_{0i} + \delta_1 BR_{t-l} + \delta_2 AR_{j,t-k}^{PUB} + \delta_3 OAR_{j,t-r}^{PUB} + \delta_4 AR_{t-m}^{PV} + \delta_5 OY_{j,t-h}^{PUB} + \\ &\quad \delta_6 Y_{t-g}^{PV} + \gamma_j Y_{j,t-1}^{PUB} + u_{i,t}, \qquad j = 1,2 \end{aligned} \tag{6}$$

where we assume that $|\gamma_i| < 1$ and $|\gamma_j| < 1$, for all *i,j* to ensure stationary, and

$Y_{i,t}^{PV}$ = Annual weighted yield index of private firm *i* in year *t*

$Y_{i,t}^{PUB}$ = Annual weighted yield index of public firm *j* in year *t*

BR_{t-l} = Basic research expenditures in year *t-l* (same for all 7 firms)

$AR_{i,t-k}^{PV}$ = Private applied research expenditures of firm *i* in year *t-k*

$AR^{PUB}_{j,t-k}$ = Public applied research expenditures of firm *j* in year *t-k*

$OAR^{PV}_{i,t-r}$ = Total applied research expenditures of other-private firms excluding firm *i* in year *t-r*

$OAR^{PUB}_{j,t-r}$ = Total applied research expenditures of other-pubic firms excluding firm *j* at year *t-r*

AR^{PV}_{t-m} = Total applied research expenditures of private firms in year *t-m*

AR^{PUB}_{t-m} = Total applied research expenditure of public firms in year *t-m*

Y^{PUB}_{t-g} = Annual weighted yield index of private firms at year *t-g*

Y^{PV}_{t-g} = Annual weighted yield index of public firms at year *t-g*

$OY^{PV}_{i,t-h}$ = Total yield index of private firms excluding firm *i* in year *t-h*

$OY^{PUB}_{j,t-h}$ = Total yield index of public firms excluding firm *j* in year *t-h*

$u_{i,t}, u_{j,t}$ = Random error terms, assumed to have multivariate normal with mean vector zero and covariance matrix Ω

This model consists of a system of 7 equations of seemingly unrelated regression: 5 for private firms and 2 for public firms. There are some interesting practical features of the above model worth mentioning. First, each of the equations in the system contains its own-lag of the dependent variable and hence this makes the system dynamic. Second, given the limitation of the current data set, we have imposed cross-equation restrictions on both private and public firms. This enables us to adequately estimate the parameters of the system. Finally, we did not represent each equation with a general distributed lag model. We chose a simpler lag structure, looking for a single lag for each variable, assuming that it will take at least 4 years from basic research and 6 years from applied research for the first successful yield to be adopted. Indeed, we have tried to specify a more general system of autoregressive distributed lag model (SADL) and we did not find any significance for the recent lag structures.

For the second and third specifications we consider are:

Model 2:

$$R^{PV}_{i,t} = \alpha_{0i} + \alpha_1 BR_{t-l} + \alpha_2 AR^{PV}_{i,t-k} + \alpha_3 OAR^{PV}_{i,t-r} + \alpha_4 AR^{PUB}_{t-m} + \alpha_5 OY^{PV}_{i,t-h} + \alpha_6 Y^{PUB}_{i,t-g} + \alpha_7 HYB^{PV}_{i,t} + \alpha_8 PBR_t + \alpha_9 TUREV^{PV}_{i,t} + \lambda_i R^{PV}_{i,t-1} + u_{i,t}, \quad i = 1,\ldots,5 \tag{7}$$

$$R^{PUB}_{j,t} = \theta_{0i} + \theta_1 BR_{t-l} + \theta_2 AR^{PUB}_{j,t-k} + \theta_3 OAR^{PUB}_{j,t-r} + \theta_4 AR^{PV}_{t-m} + \theta_5 OY^{PUB}_{j,t-h} + \theta_6 Y^{PV}_{j,t-g} + \theta_7 HYB^{PUB}_{i,t} + \theta_8 PBR_t + \theta_9 TUREV^{PUB}_{i,t} + \lambda_j R^{PUB}_{j,t-1} + u_{i,t}, \quad j = 1,2 \tag{8}$$

Model 3:

$$SR_{i,t}^{PV} = \varphi_{0i} + \varphi_1 BR_{t-l} + \varphi_2 AR_{i,t-k}^{PV} + \varphi_3 OAR_{i,t-r}^{PV} + \varphi_4 AR_{t-m}^{PUB} + \varphi_5 PBR_t + \rho_i SR_{i,t-1}^{PV} + u_{i,t}, \quad i = 1,...,5 \tag{9}$$

$$SR_{j,t}^{PUB} = \mu_{0i} + \mu_1 BR_{t-l} + \mu_2 AR_{j,t-k}^{PUB} + \mu_3 OAR_{j,t-r}^{PUB} + \mu_4 AR_{t-m}^{PV} + \mu_5 PBR_t + \rho_j Y_{j,t-1}^{PUB} + u_{i,t}, \quad j = 1,2 \tag{10}$$

where,

$R_{i,t}^{PV}$ = Revenue of private firm *i* in year *t,*

$R_{j,t}^{PUB}$ = Revenue of public firm *i* in year *t,*

$SR_{i,t}^{PV}$ = Social revenue of private firm *i* in year *t,*

$SR_{j,t}^{PUB}$ = Social revenue of public firm *i* in year *t,*

$HYB_{i,t}^{PV}$ = The proportion of the total area seeded to hybrid (HYB) varieties for private firm *i* at time *t*,

$HYB_{j,t}^{PUB}$ = The proportion of the total area seeded to hybrid (HYB) varieties for public firm *j* at time *t*,

PBR_t = Plant Breeder's Right dummy for private/public firm in year *t,*

$TUREV_{i,t}^{PV}$ = TUA (technical use agreement) revenue for private firm *i* in year *t,*

$TUREV_{j,t}^{PUB}$ = TUA (technical use agreement) revenue for public firm *j* in year *t,* and other variables defined previously as in model 1.

The specifications of model 2 and 3 are similar to those of model 1 in terms of lag structure specifications. For each model, the unknown parameters in the dynamic system, in principle, can be easily estimated by Zellner's Iterative SUR (ISUR) estimator. These estimates are consistent, asymptotically efficient, and numerically equivalent to the maximum likelihood estimator.

The ISUR estimator uses equation-by-equation OLS to construct an estimate of the disturbance covariance matrix Ω and then does the generalized least squares, given this initial estimate of Ω, on an appropriately stacked set of equations. The procedure is then iterated until the estimated parameters and the estimated Ω converge.

One estimation decision that arises in each model is how to choose the appropriate lag length. One simple way is to select the lag based on the minimum of the multivariate version of the Akaike Information Criterion (MAIC). Alternatively, given a special structure of the model, specifying different lags always results in the same number of the parameters. Consequently, minimizing the MAIC is equivalent to minimizing the determinant of residual covariance matrix. We have used this second approach to determine the appropriate lag length in each model.

Regression Results

The regression results for the three models are reported in Table 1, Table 2, and Table 3. In these tables, the sign of the estimated coefficient indicates whether an increase in the explanatory variable causes an increase (+) or decrease (-) in the dependent variable. The adjusted R-squared shows, after taking into account the degrees-of-freedom, the proportion or percentage of the total variation in the dependent variable explained by the regression model.

The results of the three regressions appear to be robust. Most of the estimated coefficients are individually statistically significant at the 5 percent level. Almost all the explanatory variables have the expected signs. The regressions have an $\overline{R}^2$ between 0.590 and 0.997 (first regression), 0.467 and 0.963 (second regression), 0.342 and 0.890 (third regression).

Model 1

The empirical results reveal that lagged basic research expenditure positively affects the annual weighted yield index of private firms, while negatively affecting the weighted yield index of public firms. Public basic research expenditure with a lag of nine periods has a coefficient of .304 in the first model, implying that, *ceteris paribus*, a $1 million increase in the annual public basic research in one year increases the private yield index after nine years by .304 index points. This positive spillover is consistent with notion that basic research increases the productivity of private applied research. In contrast to this result, a $1 million increase in the annual public basic research expenditure in one year reduces the public yield index after nine years by .2 index points. This interesting result suggests that an increase in basic research, which is located within public institutions, uses common resources within the research institution, thereby reducing the resources available for applied public research.

The firms' own-lagged applied research expenditure has a positive effect on yield. The coefficient of 2.12 for private firms (.601 the public firms) implies that a $1 million expenditure brings about an increase of 2.12 (.601) in the yield index. The much larger coefficient for the private firms suggests a higher direct productivity for private applied research. For all firms, public and private, the previous years' yields have positive signs, with coefficients less than one, and thus are consistent with dynamic stability.

Other-firms' lagged research expenditures have a spillover effect on each firm's yield index. The synergistic effect was strongest within-groups, i.e. between public firms (.35) and between private firms (.32). A somewhat smaller synergistic affect was evident between-groups in the spillover of public expenditure on applied yields (.158). These positive effects are consistent with human capital and knowledge spillovers. A negative spillover effect of .163 occurred between private firm expenditures and public firm yields. This latter between-group effect may have been generated from the pecuniary effect of private firms bidding up the cost of public research resources. During the growth phase of the industry migration tended to occur from the public sector to the private sector.

A positive spillover of within-group yields was evident while the spillover was negative between-groups. A one point increase in other-private (public) firms' yield index resulting in a .9 point (.036) increase in the firm's own-yield index. In contrast, the public yield index had a negative .448 point impact on private yield, while the reverse between-group impact was also negative but insignificant.

The results of Model 1 show that a firm's current yield index can be modeled as a function of previous research expenditure. The model revealed strong evidence of positive spillovers within the public and within the private sectors. Publicly funded basic research and applied research created a positive spillover for private yields. Other-public/private spillovers were negative in sign.

Table 1: Regression Results of Model 1

Variable	Acronym		Coefficient	t-Statistic	Prob.
Annual weighted yield index of private firms *i* in year *t* : $Y_{i,t}^{PV}$					
Annual weighted yield index of public firms *j* in year *t* : $Y_{i,t}^{PUB}$					
(dependant variables)					
Basic research expenditures in year *t-9*	BR_{t-l}	β_1	0.304	3.326	0.001
Private applied research expenditures in year *t-6*	$AR_{i,t-k}^{PV}$	β_2	2.116	8.171	0.000
Total applied research expenditures of other-private firms in year *t-6*	$OAR_{i,t-r}^{PV}$	β_3	0.320	3.813	0.000
Total applied research expenditures of public firms in year *t-7*	AR_{t-m}^{PUB}	β_4	0.158	1.831	0.069
Total yield index of -private firms in year *t-6*	$OY_{i,t-h}^{PV}$	β_5	0.903	65.945	0.000
Yield index of public firms at year *t-12*	Y_{t-g}^{PUB}	β_6	-0.448	-5.600	0.000
Yield index of private firm *1* in year *t-1*	$Y_{i,t-1}^{PV}$	γ_1	0.067	4.221	0.000
	constant	β_{01}	37.665	5.128	0.000
Yield index of private firm *2* in year *t-1*	$Y_{i,t-1}^{PV}$	γ_2	0.335	3.761	0.000
	constant	β_{02}	54.000	4.927	0.000
Yield index of private firm *3* in year *t-1*	$Y_{i,t-1}^{PV}$	γ_3	0.479	6.419	0.000
	constant	β_{03}	48.706	4.758	0.000
Yield index of private firm *4* in year *t-1*	$Y_{i,t-1}^{PV}$	γ_4	0.500	7.431	0.000
	constant	β_{04}	42.836	4.491	0.000
Yield index of private firm *5* in year *t-1*	$Y_{i,t-1}^{PV}$	γ_5	0.500	6.697	0.000
	constant	β_{05}	47.323	4.712	0.000
Basic research expenditures in year *t-9*	BR_{t-l}	δ_1	-0.200	-1.734	0.085
Public applied research expenditures in year *t-6*	$AR_{j,t-k}^{PUB}$	δ_2	0.601	2.087	0.038
Total applied research expenditures of other-public firms in year *t-6*	$OAR_{j,t-r}^{PUB}$	δ_3	0.351	3.320	0.001
Total applied research expenditures of private	AR_{t-m}^{PV}	δ_4	-0.163	-2.018	0.045

firms in year *t-7*					
Total yield index of other-public firms in year *t-6*	$OY^{PUB}_{j,t-h}$	δ_5	0.036	2.297	0.023
Yield index of private firms at year *t-12*	Y^{PV}_{t-g}	δ_6	0.000	-0.317	0.752
Yield index of public firm *6* in year *t-1*	$Y^{PUB}_{j,t-1}$	γ_6	0.521	5.251	0.000
	constant	δ_{06}	50.287	4.858	0.000
Yield index of public firm7 in year *t-1*	$Y^{PUB}_{j,t-1}$	γ_7	0.940	14.495	0.000
	constant	δ_{07}	-0.615	-0.131	0.896

Determinant residual covariance: 1.71E+12
$\overline{R}^2$: 0.590 - 0.997

Model 2

Model 2, which examined the determinants of firm revenue, also showed important spillover effects. The effect of basic research and own-firm applied research expenditures have the same signs as Model 1. An additional dollar in lagged basic research expenditure changed private (public) revenue by $.346 (-$.187). Own-firm lagged applied research increased private (public) revenue by $.480 ($.962).

The spillover effect of the lagged applied research was negative within-group and positive between-groups. A dollar increase in other-private (public) firm applied research expenditure reduced firm revenue by $.341 ($2.412). These negative impacts show a strong degree of competition within-groups. In contrast, a $1 increase in public (private) expenditure increased private revenue by $.311 ($.278), indicating positve spillovers between-groups.

The spillover of other-firms' yields tends to have a negative impact on firm revenue. This negative relationship exists amoung private firms, from private to public firms, and from public to private firms.. The exception is the public-to-public interaction, where there is synergistic impac perhaps due to a different ethos among public breeders.

The proportion of the total area seeded to hybrids and the plant breeder rights had a positive impact on private revenues, while having a negative impact on public revenue. A complete shift to hybrids would increase (reduce) private (public) revenue by $ 3.466 million ($3.996 million) per year. PBR increased (reduced) private (public) revenue by

$5.592 million ($8.14 million). The TUA fees had a positive affect on total revenue, of .94 in the case of private firms suggesting a slight reduction in the non-TUA revenue, while for the public firms, a dollar in TUA revenue tended to increase total revenue by $7.738, indicating a dramatic increase in pricing.

In summary, Model 2, which examines firm revenue, shows evidence of the pecuniary impacts of competition between-firms, particularly within-groups. Applied expenditure within-group reduces other-firm revenue, while between-group spillovers are positive. Higher lagged yield of competing firms has a negative impact on revenue, with the exception of public-to-public impacts, which are positive. Property rights and hybrid technologies have a positive effect on private sales revenue and a negative impact on public revenue.

Table 2: Regression Results of Model 2

Variable	Acronym		Coefficient	t-Statistic	Prob.
Revenue of private firm *i* in year *t*: $R_{i,t}^{PV}$					
Revenue of public firm *j* in year *t*: $R_{j,t}^{PUB}$					
(dependent variables)					
Basic research expenditures in year *t-7*	BR_{t-l}	α_1	0.346	2.777	0.006
Private applied research expenditures in year *t-9*	$AR_{i,t-k}^{PV}$	α_2	0.480	1.854	0.065
Total applied research expenditures of other-private firms in year *t-9*	$OAR_{i,t-r}^{PV}$	α_3	-0.341	-1.852	0.066
Total applied research expenditures of public firms in year *t-8*	AR_{t-m}^{PUB}	α_4	0.311	2.725	0.007
Total yield index of other-private firms in year *t-9*	$OY_{i,t-h}^{PV}$	α_5	-0.309	-6.477	0.000
Yield index of public firms at year *t-12*	Y_{t-g}^{PUB}	α_6	-0.305	-2.663	0.009
Revenue of private firm *1* in year *t-1*	$R_{i,t-1}^{PV}$	λ_1	1.199	7.258	0.000
The proportion of the total area seeded to hybrid (HYB) varieties for private firm at time *t*	$HYB_{i,t}^{PV}$	α_7	3.466	2.678	0.008
Plant Breeder's Right dummy for private/public firm in year *t*	PBR_t	α_8	5.592	2.992	0.003
TUA (technical use agreement) revenue for private firm in year *t*	$TUREV_{i,t}^{PV}$	α_9	0.943	11.966	0.000
	constant	α_{01}	24.777	2.377	0.019
Revenue of private firm2 in year *t-1*	$R_{i,t-1}^{PV}$	λ_2	0.412	3.763	0.000
	constant	α_{02}	25.347	2.434	0.016
Revenue of private firm *3* in year *t-1*	$R_{i,t-1}^{PV}$	λ_3	0.882	14.516	0.000
	constant	α_{03}	22.105	2.115	0.036
Revenue of private firm *4* in year *t-1*	$R_{i,t-1}^{PV}$	λ_4	0.497	6.137	0.000
	constant	α_{04}	25.885	2.492	0.014
Revenue of private firm *5* in year *t-1*	$R_{i,t-1}^{PV}$	λ_5	0.636	10.483	0.000
	constant	α_{05}	25.844	2.484	0.014

Basic research expenditures in year *t-7*	BR_{t-l}	θ_1	-0.187	-0.639	0.524
Public applied research expenditures in year *t-9*	$AR^{PUB}_{j,t-k}$	θ_2	0.962	3.231	0.002
Total applied research expenditures of other-public firms in year *t-9*	$OAR^{PUB}_{j,t-r}$	θ_3	-2.412	-4.159	0.000
Total applied research expenditures of private firms in year *t-8*	AR^{PV}_{t-m}	θ_4	0.278	1.050	0.295
Total yield index of other-public firms in year *t-9*	$OY^{PUB}_{j,t-h}$	θ_5	0.247	1.816	0.071
Yield index of private firms at year *t-12*	Y^{PV}_{t-g}	θ_6	0.00022	-2.740	0.007
Revenue of public firm *6* in year *t-1*	$R^{PUB}_{j,t-1}$	λ_6	0.437	3.428	0.001
The proportion of the total area seeded to hybrid (HYB) varieties for public firm at time *t*	$HYB^{PUB}_{i,t}$	θ_7	-3.996	-0.842	0.401
Plant Breeder's Right dummy for private/public firm in year *t*	PBR_t	θ_8	-8.140	-1.628	0.105
TUA (technical use agreement) revenue for public firm in year *t*	$TUREV^{PUB}_{i,t}$	θ_9	7.738	1.393	0.165
	constant	θ_{06}	41.328	4.419	0.000
Revenue of public firm *7* in year *t-1*	$R^{PUB}_{j,t-1}$	λ_7	0.383	2.714	0.007
	constant	θ_{07}	-16.897	-1.160	0.248

Determinant residual covariance: 6.83E+08
$\overline{R}^2$: 0.467 - 0.963

Model 3

The estimates of model 3 show how the social revenue associated with the varieties of each firm are affected by research expenditures and PBR. The results are very similar in sign to those estimated in model 2.

A $1 increase in lagged basic research increased (reduced) private (public) social revenue by $.806 ($5.727). This indicates that the output of the private firms is positively affected by basic research; the public output seems to be a decreasing function of basic research expenditure.

The applied research investment in each firm increases the social revenue associated with its varieties. In the case of private (public) firms a $1 increase in applied research resulted in an increase in social revenue of $1.846 (5.236). These figures are much larger than the increase in private revenue reported in Model 2, indicating a gap between private and social revenue and a significant positive spillover to downstream research users. The other-firms' research expenditure has a negative impact within-group and a positive impact between-groups. A $1 increase in a private (public) firms competitor's applied research reduced the firm's associated social revenue by $1.962 ($6.243). An increase in private (public) applied research increased the social revenue associated with public (private) varieties by $1.06 ($2.195). Comparing the significantly smaller own-research impacts to the larger negative spillovers would suggest that an increase in applied research may have a negative impact social revenue.

PBRs have a strong positive effect on the impact of private research and strong negative impact on the products of public applied research. The estimates suggest that PBRs increased the social revenue associated with private varieties by $29.95 million while reducing revenue associated with public applied research by $42.47 million. This is a very substantial shift and probably reflects other changes in research policy that coincided with PBRs including the introduction of the practice to transfer public varieties to public firms for commercialization.

In summary, model three shows the social revenue associated with the output of a firm can be estimated as a function lagged research expenditure and PBRs. The results are consistent with model 2 and show that competition within-group is much stronger than between-groups. The fact that the estimated coefficients for social revenue from the own-applied research is greater than the private revenue coefficients suggests a significant spillover of benefits to downstream research users. The fact that the across-firm negative spillovers from applied research are greater that the positive own-firm effects suggests there could be an overexpenditure in the industry. The introduction of PBRs coincided with a major change in the social revenue associated with private and public vareities.

Table 3: Regression Results of Model 3

Variable	Acronym		Coefficient	t-Statistic	Prob.
Social revenue of private firm *i* in year *t*: $SR_{i,t}^{PV}$					
Social revenue of public firm *j* in year *t*: $SR_{j,t}^{PUB}$					
(dependant variables)					
Basic research expenditures in year *t-7*	BR_{t-l}	φ_1	0.806	2.273	0.024
Private applied research expenditures in year *t-11*	$AR_{i,t-k}^{PV}$	φ_2	1.846	1.730	0.085
Total applied research expenditures of other-private firms in year *t-8*	$OAR_{i,t-r}^{PV}$	φ_3	-1.962	-3.774	0.000
Total applied research expenditures of public firms in year *t-13*	AR_{t-m}^{PUB}	φ_4	1.067	2.284	0.024
Social revenue of private firm *1* in year *t-1*	$SR_{i,t-1}^{PV}$	ρ_1	0.764	7.001	0.000
	constant	φ_{01}	-3.569	-0.634	0.527
Plant Breeder's Right dummy for private/public firm in year *t*	PBR_t	φ_5	29.947	5.083	0.000
Social revenue of private firm *2* in year *t-1*	$SR_{i,t-1}^{PV}$	ρ_2	0.221	2.043	0.043
	constant	φ_{02}	-4.157	-1.163	0.246
Social revenue of private firm *3* in year *t-1*	$SR_{i,t-1}^{PV}$	ρ_3	0.726	9.972	0.000
	constant	φ_{03}	0.088	0.013	0.990
Social revenue of private firm *4* in year *t-1*	$SR_{i,t-1}^{PV}$	ρ_4	0.697	9.390	0.000
	constant	φ_{04}	-14.000	-1.286	0.200
Social revenue of private firm5 in year *t-1*	$SR_{i,t-1}^{PV}$	ρ_5	0.697	8.560	0.000
	constant	φ_{05}	-1.597	-0.292	0.771
Basic research expenditures in year *t-7*	BR_{t-l}	μ_1	-5.727	-3.173	0.002
Public applied research expenditures in year *t-11*	$AR_{j,t-k}^{PUB}$	μ_2	5.236	2.981	0.003
Total applied research expenditures of other-public firms in year *t-8*	$OAR_{j,t-r}^{PUB}$	μ_3	-6.243	-3.117	0.002
Total applied research expenditures of private firms in year *t-13*	AR_{t-m}^{PV}	μ_4	2.915	1.215	0.226

Social revenue of public firm *6* in year *t-1*	$SR^{PUB}_{j,t-1}$	ρ_6	0.425	3.377	0.001
	constant	φ_{06}	210.067	5.205	0.000
Plant Breeder's Right dummy for private/public firm in year *t*	PBR_t	μ_5	-42.473	-1.851	0.066
Social revenue of private firm *7* in year *t-1*	$SR^{PUB}_{j,t-1}$	ρ_7	0.587	4.642	0.000
	constant	φ_{07}	62.267	3.526	0.001

Determinant residual covariance: 3.63E+18
$\overline{R}^2$: 0.342 - 0.890

V. Conclusions

Despite the theoretical importance of research spillovers, the lack of firm-specific data has hampered the empirical analysis of these effects. In this paper we used firm-specific data in the canola industry to empirically examine a number of research spillovers among public and private firms. The spillovers were examined at the level of research output, research sales revenue, and research social revenue. The non-pecuniary spillovers examined include the spillovers from basic research, the spillovers of human capital and knowledge (as measured through other-firm expenditures), and genetic spillovers (as measured through yields of other-firm's seeds). The pecuniary spillovers from market impacts are examined through the private and social revenue functions.

The results of the empirical study show that firm variety yield indexes can be modeled as a function of previous research expenditure, and revealed strong evidence of positive spillovers within the public and within the private sector. Basic research and public applied research created a positive spillover for private firms. In a second model, which examined firm revenue, there was evidence of the pecuniary impacts of competition between-firms, particularly within-groups. Applied expenditure within-group reduces other-firm revenue, while between-group spillovers are positive. Property rights and hybrid technologies have a positive effect on private sales revenue and a negative impact on public revenue. The social revenue associated with the output of a firm can be estimated as a function of lagged research expenditure and PBRs. The results show that competition within-group is much stronger than between-groups. The fact that estimated coefficients for social revenue are larger from the own-applied research than for the private revenue coefficients suggest a significant spillover of benefits to downstream research users. Across-firm negative spillovers from applied research that are larger than the positive own-firm effects suggest there could be an overexpenditure in the industry. Overall, the results provide strong empirical evidence that a number of research spillovers were important in the biotech crop research industry.

This preliminary empirical analysis provides strong evidence that research spillovers are important. A number of interesting results from this study strongly suggest that more analysis is needed to explore and understand the implications of research spillovers for the biotech industry and for research policy in general.

References

Acs, Z.J., D.B. Audretsch, and M.P. Feldman. 1994. "R&D Spillovers and Recipient Firm Size." *Review of Economics* 76(2): 336-40.

Adams, J.D. 1999. "The Structure of Firm R&D, The Factor Intensity of Production, and Skill Bias." *Review of Economics and Statistics* 81(3): 499-510.

Adams, J.D. 2000. "Endogenous R&D Spillovers and Industrial Research Productivity." Working Paper 7484. National Bureau of Economic Research, Cambridge, MA, January 2000.

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

Adams, J.D., and A.B. Jaffe. 1996. "Bounding the Effects of R&D: An Investigation Using Matched Firm and Plant Level Data." *Rand Journal of Economics* 27: 700-21.

Aghion, P., and P. Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica* 60: 323-351.

Alberta Agriculture and Food. 2002, 2003. *2003 Agronomic Performance Data for all Crops and Regions.* http://www.agric.gov.ab.ca/crops/performance/all.html. November-January.

Alberta Crop Insurance Corporation. 2002. Obtained through personal communication with Murray Hartman, Extension Agronomist, Alberta Agriculture and Food. December.

Alberta Seed Industry. *New in 2001: Canola, Flax, and Mustard Varieties – 2001.* http://www.seed.ab.ca/var/sum/gmcanola01.shtml. January.

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

Blais, David. 2003. Agronomist, North Eastern Alberta and North Western Saskatchewan. Canola Council of Canada. Personal Communication. January.

Canola Council of Canada. 2002,2003. *Argentine Varieties and Polish Varieties.* http://www.canola-council.org/production/2_varint.html. November-January.

Canola Council of Canada. 2002. *Economic Analysis: CPC Annual Reports* (Various Years). http://www.canola-council.org/ (1998-2001). November. From 1991 to 1997, Obtained through personal communication with Dave Wilkins, Director of Communications, Canola Council of Canada.

Canola Research Survey. 1999. University of Saskatchewan, Department of Agricultural Economics: Saskatoon, SK.

CFIA (Canadian Food Inspection Agency). 1998. *Canadian Varieties. January 1, 1923 to June 24, 1998*. Special Tabulation from the Plant Health and Production Division. (http://inspection.gc.ca).

CFIA (Canadian Food Inspection Agency). 2002, 2003. *Status of PBR Applications and Grant of Rights: Complete list of Varieties*. http://www.inspection.gc.ca/english/plaveg/pbrpov/croproe.pdf. November-January.

CFIA (Canadian Food Inspection Agency). 2002. http://inspection.gc.ca/english/plaveg/variet/rapecole.shtml. June.

Cohen, W.M. and D.A. Levinthal. 1989. "Innovation and Learning: The Two Faces of R&D." *Economic Journal* 99: 569-97.

Dasgupta, P., and J. Stiglitz. 1980. "Industrial Structure and the Nature of Innovative Activity." *The Economic Journal* 90: 266-293.
David, P.A., and B.H. Hall. 2000. "Heart of Darkness: Modeling Public-Private Funding Interactions Inside the R&D Black Box." A report prepared for a special issue of *Research Policy*. Cambridge, MA: National Bureau of Economic Research.
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.
Evenson, R.E. 1989. "Spillover Benefits of Agricultural Research: Evidence from US Experience." *American Journal of Agricultural Economics* 71(2): 447-52.
Evenson, R.E., and Y. Kislev. 1976. "A Stochastic Model of Applied Research." *Journal of Political Economy* 84: 265-281.
Griliches, Z. 1979. "Hybrid Corn Revisited: A Reply." *Econometrica* 48(6): 1463-65.
Griliches, Z. 1980. "Issues in Assessing the Contribution of Research and Development to Productivity Growth." *Bell Journal of Economics* 10(1): 92-116.
Griliches, Z. 1992. "The Search for R&D Spillovers." *Scandinavian Journal of Economics* 94(supplement): 29:47.
Heisey, P, and M.L. Morris. 2002. Practical Challenges to Estimating the Benefits of Agricultural R&D: The Case of Plant Breeding Research." Selected paper for presentation at the *American Agricultural Economic Association Meetings*, Long Beach, California, July 2002.
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. http://res2.agr.ca/icar/english/tableofcontents.htm.
ICAR (Inventory of Canadian Agri-Food Research). 2000. Special Tabulation upon Request. http://res2.agr.ca/icar/english/tableofcontents.htm.
ISI (Institute for Scientific Investigation). 1997. Citations Database, Special Tabulation of Academic Publications Based on Key Word Search for Canola. November, 1997.
Jaffe, A.B. 1986. "Technological Opportunity and Spillovers of R&D: Evidence from Firm's Patents, Profits, and Market Value." *American Economic Review* 76: 984-1001.
Johnson, D.K.N., and R.E. Evenson. 1999. "R&D Spillovers to Agriculture: Measurement and Application." *Contemporary Economic Policy* 17: 432-456.
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.

Kortum, S. 1997. "Research, Patenting, and Technological Change." *Econometrica* 65: 1389-419.
Lee, T.K. 1982. "A Nonsequential R&D Search Model." *Management Science* 28(8): 900-909.
Lee, T.K. 1985. "On the Joint Decisions of R&D and Technology Adoption." *Management Science* 31(8): 959-969.
Levin, R.C. and P.C. Reiss. 1984. "Test of Schumpeterian Model of R&D and Market Structure," In Z. Griliches, ed., *R&D, Patents, and Productivity*. Chicago: University of Chicago Press.
Levin, R.C. and P.C. Reiss. 1988. "Cost-reducing and Demand-Creating R&D with Spillovers." *RAND Journal of Economics* 19: 538-56.
Lucas, R. 1988. "On The Mechanics of Economic Development." *Journal of Monetary Economics* 22(1): 3-42.
Manitoba Agriculture and Food. 2003. *2003 Variety Guide for Oilseeds and Special Crops*. http://www.gov.mb.ca/agriculture/crops/oilseeds/pdf/bga01s08.pdf. January.
Manitoba Crop Insurance Corporation. 2002. Manitoba's Management Plus Program. *Regional Variety Yield Analysis (1991-2001)*. http://www.mmpp.com/Information_Page.htm. December.
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.* University of Saskatchewan, Department of Agricultural Economics: Saskatoon, SK.
Pardey, P.G., J.M. Alston, J.E. Christian, and S. Fan. 1996. *Hidden Harvest: U.S. Benefits from International Research Aid*. Food Policy Report. Washington, D.C.: International Food Policy Research Institute (IFPRI).
Paterson, N.M. and Sons. Limited Grain Buyer. 2003. *Polish and Argentine Canola Varieties*. http://www.patersongrain.com/cropinputs.html. January.
Phillips, P. 1997. Manual search of ISI Citations Index, July.
Prairie Pools Inc. Various Issues. *Prairie Grain Variety Survey 1977-1992.* Regina, SK.
Roberts, R.D. 1984. "A Positive Model of Private Charity and Public Transfers." *Journal of Political Economy* 92: 136-148.
Robson, M. 1993. Federal Funding and the Level of Private Expenditure on Basic Research. *Southern Economic Journal*, 60: 63-71.
Rogers, Jim. 2003. Certified Seed Grower. Personal Communication. January.
Romer, P. 1986. "Increasing Returns and Long-Run Growth." *Journal of Political Economy* 94: 1002-37.
Romer, P. 1990. "Endogenous Technological Change." *Journal of Political Economy* 98(2): S71-S102.
Saskatchewan Agriculture and Food. 2002. *Agricultural Statistics*. Saskatchewan Agriculture and Food: Regina, SK.
Saskatchewan Agriculture and Food. Various Issues. *Varieties of Grains Crops in Saskatchewan.* Saskatchewan Agriculture and Food: Regina, SK.

SeCan. 2002. *Prices, Royalties and volumes*. Obtained through personal communication with L.R. White, General Manager, SeCan, Ottawa, Ontario. November.

Spence, A.M. 1984. "Cost Reduction, Competition, and Industry Performance." *Econometrica* 52: 1001-21.

Statistics Canada. 2002. *Direct Cansim Time Series: Prairie Provinces; Seeded Area; Canola (Rapeseed).* http://datacenter2.chass.utoronto.ca/cgi-bin/cansim2/getSeriesData.pl?s=V169455&b=&e=&f=plain. December.

Statistics Canada. 2003. *Direct Cansim Time Series: CPI and All Goods for Canada*. *Direct Cansim Time Series: CPI and All Goods for Canada*. http://datacenter2.chass.utoronto.ca/cgi-bin/cansim2/getSeriesData.pl?s=V735319&b=&e=&f=plain. January.

White, F.C., S. He, and S. Fletcher. 2003. "Research Spillovers and Returns to Wheat Research Investment." Selected paper for presentation at the *Southern Agricultural Economics Association Annual Meeting*, Mobile, Alabama, February 2003.

Yee, J., and W. Huffman. 2001. "Rates of Return to Public Agricultural Research in the Presence of Research Spillovers." Presentated at the *American Agricultural Economic Association Meetings*, Chicago, Illinois, August 2001.