Pecuniary, Non-Pecuniary, and Downstream Research Spillovers: The Case of Canola

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Abstract

This paper develops an empirical framework for estimating a number of inter-firm and downstream research spillovers in the canola crop research industry. The spillovers include basic research, human capital/ knowledge (as measured through other-firm expenditures), and genetics (as measured through yields of other-firms). The model used to examine spillover effects on research productivity provides evidence that there are many positive inter-firm non-pecuniary research spillovers, which is consistent with a research clustering effect. The second model, which examines spillovers at the level of firm revenue, shows that, while private firms tend to crowd one another, public firm expenditure on basic and applied research creates a crowding-in effect for private firms. This model also shows that enhanced intellectual property rights have increased the revenues of private firms. The third model, which examines social value of each firm's output, provides evidence that downstream research spillovers remain important in this modern crop research industry.

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1.0 Introduction

Intellectual Property Rights (IPRs) have fundamentally altered the nature of agricultural research spillovers. During most of the 20th century, the public good attributes of research were 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 ability of modern biotechnology to identify DNA, combined with regulatory and judicial moves to enhance IPRs, has reduced these spillovers, resulting in substantial private investment in agricultural research (Fernandez-Cornejo, 2004). 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 (see, e.g., Lindner, 1999; Fulton and Giannakas, 2001), so much so that US antitrust regulators have made recent biotech acquisitions subject to divestiture in order to limit market concentration (Schimmelpfennig, Pray, and Brennam, 2004). At the same time, more than 200 public research institutions have moved to create offices of technology transfer to manage access to their intellectual property (Graff et al., 2003) and national governments have passed laws to protect landrace genetics (Evenson, 1999; Falcon and Fowler, 2002). The combination of these effects represents a watershed of change within the agricultural research industry.

The change in crop research has been particularly evident in the Canadian canola 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 funded about 60% of the total investment in research, and owned 85% of the new varieties (Gray, Malla, and Phillips, 2002). 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 (Malla, Gray, and Phillips, 2003). Despite the importance of these changes in crop research, a lack of firm-specific data hampered the analysis and understanding of the biotech industry.

This study uses firm-specific data in the Canadian canola industry to examine a number of research spillovers among public and private firms. The effect of "spill-ins" is examined at the firm level in terms of their impact on research output, sales revenue, and a measure of downstream "social" value. The potential sources of pecuniary and non-pecuniary spillovers examined include basic research by public institutions, human capital and knowledge (as measured through other-firm expenditures), and genetic spillovers (as measured through variety yields of other-firms). Inferences about downstream spillovers and market-driven pecuniary spillovers are made from a comparison of the estimated relationships.

The methodological contribution of the paper is to develop a set of empirical models that distinguish between many types of potential spillovers within a crop research industry. Empirically we are able to show that positive inter-firm and downstream research spillovers have been important in the modern canola research industry and that public basic and applied research has caused a "crowding in" of private research activities.

The remainder of the paper is organized into three sections. Section 2 outlines relevant literature. Section 3 describes the theoretical framework used for this analysis. The empirical model and the results are reported in Section 4. Section 5 contains the concluding comments of the paper.

2. Research Spillovers

Research spillovers are central to the economics of research. These externalities that arise from the public good aspects of knowledge are an important determinant of economic productivity (e.g., Griliches, 1992; Jaffe, 1986; Adams 1990). The non-rival nature of research output 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 firm behaviour (e.g., Adams, 2000; Cohen and Levinthal, 1989; Just and

Hueth, 1993; Moschini and Lapan, 1997) and industrial organization (e.g., Spence, 1984; Dasgupta and Stiglitz, 1980; Levis and Reiss, 1984, 1988; Fulton, 1997; Lessor, 1997; Fulton and Giannakas, 2001), and industrial structure (Acs et al., 1994; Schimmelpfinnig, Pray, and Brennan, 2004).

A significant body of economic research has addressed the spillovers from public research by examining the crowding effects of public research investment on private research investment. Roberts (1984), Bergstrom et al. (1986), and David and Hall (2000) argue that publicly funded research competes for scarce resources and therefore could "crowd out" privately funded research. 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. David, Hall and Toole (1999) provided a recent survey of the available empirical evidence and found that the results were inconclusive in terms of the direction and the magnitude of the relationship between public and private research expenditure.

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; Alston and Pardey, 1996).

Some economists have distinguished between the various sources of research spillovers. Pardey et al. (1996) examined the genetic research spillovers through pedigree attribution among different breeding programs, which applies when crop pedigrees are known (Heisey and Morris 2002). The seminal work of Evenson and Kislev (1976) introduced the notion of basic research spillovers, using a theoretical model where the outputs of basic research (i.e., scientific knowledge) improve the productivity of the search process (i.e., applied research). This concept was used in a number of later studies (e.g., Lee 1982, 1985; Kortum, 1997). Diamond (1999) and Robson (1993) empirically examined the crowding effects of basic research. Finally, a number of studies have recognized that knowledge is embodied in human capital and that spillovers occur with the education of workers (e.g. Shultz, 1975, Lucas 1993), learning from others (Foster and Rosenzweig, 1995; Thorton and Thompson, 2001), and with the mobility of workers (Glaeser et al.,1992).

To estimate inter-industry spillovers it is important to distinguish between pecuniary spillovers and non-pecuniary spillovers. Pecuniary spillovers are the firm-to-firm interactions that occur through prices in a properly functioning market as the firms purchase inputs, and sell output. Non-pecuniary spillovers are the non-market impacts of a firm's actions on other firms. These spillovers typically exist because of poorly defined property rights or other forms of market failure. These spillovers are the focus of most economic analysis, because they distort private incentives away from efficient marginal conditions. The combined effects of pecuniary and non-pecuniary spillovers are important because they measure the net effect of a firm's actions on its rivals. When the combined spillover from an increase in output is negative, firms will tend to "crowd out" their rivals. In the case of positive combined spillovers this will tend to create a "crowding in" of other firms, or a research clustering effect.

3. Modelling the Impact of Research Spillovers

In Canada's canola industry both public and private research firms expend resources to develop enhanced canola varieties. Private firms engage in applied research to produce enhanced crop varieties, which are sold to farmers. Public institutions (firms) also engage in a significant amount of basic research, which creates knowledge that is used to improve crop research processes. The varieties created by public firms are distributed through the private seed industry in return for royalty payments.

The empirical model considers several possible pecuniary and non-pecuniary spillovers, which are illustrated in Figure 1. The solid arrows in the figure represent both upstream and downstream market linkages, which are the source of pecuniary spillovers. The potential non-

pecuniary spillovers are shown as dashed arrows. The non-pecuniary spillover between the firms and the downstream industry (labelled as 1) are those benefits provided to those firms and consumers that are outside of the market (e.g., benefits associated with farmers retaining seed of a new variety for the next year). The possible combinations of inter-firm non-pecuniary spillovers are labelled separately and shown as: private to private, 2a; private to public, 2b; public to private, 2c; and public to public, 2d. These inter-firm non-pecuniary spillovers can be further broken into: i) spillovers generated from the germplasm of other firms, ii) spillovers generated from knowledge created by the applied research of other firms, and iii) spillovers generated from the knowledge created by the basic research of public firms.[1]

{Figure 1 goes about here}

In the econometric model to follow, we model the firm-to-firm spillovers in three different models: *Model 1*) at the level of each firm's production function for new varieties; *Model 2*) at the level of each firm's sales revenue; and *Model 3*) at the level of the social benefits embodied in each firm's varieties. Model 1 allows us to isolate the inter-firm non- pecuniary spillover effects. Model 2, based on revenue, will capture both the non-pecuniary spillovers and the pecuniary spillovers generated by the other firms in the output market, providing an indication of the crowding effects. The measure of firm output in Model 3 includes the spillovers to downstream firms and consumers, giving an indication of some of the social impacts of inter-firm spillovers. In the estimation we make a further distinction between public and private research enterprises such that the inter-firm spillovers within the public or private sector are potentially different than the private-pubic spillovers.

Model 1:

Research outputs, the dependent variables in Model 1, are measured as the average yield of new varieties sold by each firm each year. The production function of each research firm is described by the function:

$$Y_{it} = f(\underset{+}{Y_{i,t-1}}, \underset{+}{AR_{i,t-k}}, \underset{+}{BR_{t-l}}, \underset{+}{OAR_{i,t-r}}, \underset{+}{OY_{i,t-m}}),$$ (1)

where Y_{it} is the average yield of new varieties of firm i in year t, which is an increasing function of the previous period's yield, $Y_{i,t-1}$, lagged own applied research, $AR_{i,t-k}$,[2] and, through non-pecuniary spillovers, an increasing function of lagged basic research expenditures, BR_{t-m}, lagged applied expenditure of other-firms, $OAR_{i,t-r}$, and the lagged yield of other-firms, $OY_{i,t-m,}$.

In Model 1 the derivative of output with respect to the own applied research is the single-year marginal product (in terms of yield increase) of an additional unit of applied research. The derivative with respect to the lagged own yield represents the marginal persistence effect. The marginal impact of the spillovers on a firm's output, from public basic research, its rival's applied research, and its rivals' yield levels, are also captured in the derivative of the function.

Model 2:

The dependent variables in this model are the revenues of each firm i in each year t, which consists of 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,

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

In this case sales revenue, $R_{i,t}$, is an increasing function of last year's revenue, $R_{i,j-1}$, own lagged applied research, $AR_{i,t-k}$, plant breeders' rights, PBR_t, the proportion of area seeded to varieties requiring annual repurchase, HYB_{it}, and technical use revenue, $TUREV_{i,t}$. The latter three variables measure strengthened IPRs and greater ability to capture revenue, and therefore each should be positive. The spillovers from lagged basic research, BR_{t-l}, other-firms' applied research expenditure, $AOR_{i,t-k}$, 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. For Model 2, the derivatives of the function represent the private marginal revenue effects.

Model 3:

This model 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 yield's increases 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 canola prices. The spillovers at this level will include both pecuniary and non-pecuniary inter-firm spillovers, as well as the downstream spillovers. The social revenue for firm *i* in period *t* can be described as:

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

Social revenue, $SR_{i,t,}$, is expected to be an increasing function of the firm's lagged applied research, $AR_{i,t-k}$, and the previous period social revenue, $SR_{i,t-1}$. The market-correcting effect of plant breeders' rights, PBR_t, is ambiguous in the presence of other spillovers, given Lancaster's argument of the second best. The spillovers from lagged basic research, BR_{t-l}, and other-firms' lagged applied research, $OAR_{i,t-r}$, will be negative (positive) if the social pecuniary effects are greater (less) than non-pecuniary spillover effects. The derivatives of Equation 3 represent the marginal impacts of each variable firm on the sum of firm revenue and downstream spillovers.

4. Econometric Analysis

4.1 Data and Econometric Model Specification

The data used for the econometric analysis came from many industry and government sources and in some cases took considerable calculation to construct each of the variables used for the econometric analysis. We were able to construct a data set for five private firms and two public institutions. The primary data source for research expenditures was a survey of the Canola Industry (Canola Research Survey, 1999). These data sources and the methodology used to construct each variable are described in Appendix A.

We used three different models for the analysis of research spillovers. To separate research spillovers effects in public firms and private firms, we divided the firms into two groups: private firms and public firms. In the first model, we considered the following specification:

Model 1:

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

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

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*

$Y_{j,t}^{PUB}$ = 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*

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

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

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

AR_{t-m}^{PV} = Total applied research expenditures of private firms in year t–m

AR_{t-m}^{PUB} = Total applied research expenditure of public firms in year t–m

Y_{t-g}^{PUB} = Annual weighted yield index of private firms at year t–g

Y_{t-g}^{PV} = Annual weighted yield index of public firms at year t–g

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

$OY_{j,t-h}^{PUB}$ = 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. Some interesting practical features of the model are worth mentioning. First, each of the equations in the system contains its own-lag of the dependent variable, so the system is 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.

The second and third specifications we consider are:

Model 2:

$$R_{i,t}^{PV} = \alpha_{0i} + \alpha_1 AR_{i,t-k}^{PV} + \alpha_2 BR_{t-l} + \alpha_3 OAR_{i,t-r}^{PV} + \alpha_4 AR_{t-m}^{PUB} + \alpha_5 OY_{i,t-h}^{PV} +$$

$$\alpha_6 Y_{i,t-g}^{PUB} + \alpha_7 HYB_{i,t}^{PV} + \alpha_8 PBR_t + \alpha_9 TUREV_{i,t}^{PV} + \lambda_i R_{i,t-1}^{PV} + u_{i,t}, \qquad i = 1,...,5 \tag{7}$$

$$R_{j,t}^{PUB} = \theta_{0j} + \theta_1 AR_{j,t-k}^{PUB} + \theta_2 BR_{t-l} + \theta_3 OAR_{j,t-r}^{PUB} + \theta_4 AR_{t-m}^{PV} + \theta_5 OY_{j,t-h}^{PUB} +$$

$$\theta_6 Y_{j,t-g}^{PV} + \theta_7 HYB_{i,t}^{PUB} + \theta_8 PBR_t + \theta_9 TUREV_{i,t}^{PUB} + \lambda_j R_{j,t-1}^{PUB} + u_{i,t}, j = 1,2 \tag{8}$$

Model 3:

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

$$i = 1,...,5$$

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

$$j = 1,2$$

where, we assume again, $|\lambda_i| < 1$, $|\lambda_j| < 1$, $|\rho_i| < 1$ and $|\rho_j| < 1$ for all i, j, and

$R_{i,t}^{PV}$ = 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 Breeders' Rights 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 Models 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.

4.2 Regression Results

The regression results for the three models reported in Table 1, Table 2, and Table 3 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 $\overline{R}^2$ 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 firms' own-lagged applied research expenditure has a positive effect on yield. The coefficient of 2.12 for private firms (0.601 for public firms) implies that a $1 million expenditure increases the yield index by 2.12 (0.601). 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.

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.

{Table 1 about here }

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 private firms bidding highly qualified personnel away from the public sector. During the growth phase of the industry, migration tended to occur from the public sector to the private sector.

A positive spillover was evident for yields within group while the spillover was negative between groups. A one-point increase in other-private (public) firms' yield index resulted 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 modelled 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.

Model 2

Model 2, which examines the determinants of firm revenue, revealed that one dollar of own-firm lagged applied research increased private (public) revenue by $.480 ($.962). This model also showed important spillover effects. In this case the spillovers include pecuniary effects in the output market and therefore illuminate crowding effects. An additional dollar in lagged basic research expenditure changed private (public) revenue by $.346 (–$.187), indicating that public basic research provides monetary benefits to private industry, while drawing resources away for public-firm applied research.

{Table 2 about here}

The inter-firm spillover effects of lagged applied research were negative within groups. A dollar increase in other-private (public) firm applied research expenditure reduced firm revenue by $.341 ($2.412). Given that there were positive spillovers in production, these negative impacts show a strong degree of competition within groups, which is not surprising since the firms are competing for the same customers.

In contrast to the within-group competition, a $1 increase in public (private) expenditure increased private revenue by $.311 ($.278), indicating positive spillovers between groups. This indicates that non-pecuniary spillovers dominate the pecuniary spillovers such that public applied research activity has crowded in private research, rather than crowding it out.

The spillover of other-firms' yields tends to have a negative impact on firm revenue. This negative relationship exists among 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 impact, perhaps due to a different ethos among public breeders.

The variables for proportion of the total area seeded to hybrids and for plant breeders' 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, .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.

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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. A higher lagged yield for competing firms has a negative impact on revenue, with the exception of public-to-public impacts, for which it is positive. Property rights and hybrid technologies have a positive effect on private sales revenue and a negative impact on public revenue.

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 PBRs. The results are similar in sign to the private revenue estimated in Model 2.

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, particularly in the case of public applied research.

{Table 3 about here}

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

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 could 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 of transferring public varieties to public firms for commercialization.

In summary, Model 3 shows that 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 that between groups. The fact that the estimated coefficients for social revenue from the own-applied research are 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 than the positive own-firm effects suggests there could be an over expenditure in the industry. The introduction of PBRs coincided with a major change in the social revenue associated with private and public varieties.

5. Conclusions

This study examined many research spillovers in a modern crop research industry as delineated by: their public or private source; their public or private incidence; whether they were generated through basic research, applied research activity, or germplasm; and whether they were inter-firm pecuniary, inter-firm non-pecuniary, or downstream in nature. The empirical framework, which estimated a production function, a private revenue function and a social revenue, provided a useful conceptual separation of research spillovers, and provided a broad scope of empirical results with many implications for private incentives and research policy.

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The three empirical models fit the data well and provided theoretically plausible estimates. Lagged applied research investment by each firm increased research output, research revenue, social research revenue. Enhanced IPRs increased private research revenue, and the social value of their innovations. Perhaps the most striking general result was the ubiquitous presence of research spillovers in each model.

The empirical results of Model 1 provide the strongest evidence of non-pecuniary spillovers. The results show that public basic research, public applied research, and other firm private applied research, and other private firm varieties, created a positive spillover for private firms. These spillovers indicate that public research has made private research firms more productive, and private firms may benefit from the knowledge generated from their rivals.

The empirical results of Model 2 provide estimates of the total (pecuniary plus non-pecuniary) research spillovers. The results show that, while private firms have a net competitive or crowding-out effect, public firm basic and applied research enhances private revenue, creating a crowding-in effect. This model also shows that plant breeders' rights, proprietary technologies, and technical use agreements enhance private firms' ability to generate revenue.

Model 3 empirically estimates the social value of sales from each firm. The much larger coefficients than those estimated in Model 2 provide evidence of considerable downstream research spillovers in the canola industry. Spillovers from public basic and applied research have enhanced the social value of firm output. The large impact of the plants breeders' rights represents a significant structural change that significantly increased the social value of private firms' output while reducing the social value of sales from public institutions.

The results of the empirical analysis have several implications for research policy. The most apparent is that public and private research firms are integrally linked through numerous types of research spillovers. Publicly funded basic and applied research both had positive effects on private research productivity, profitability, and social value output. The negative impact of basic research on public firm output and revenue suggests that these basic research activities are underreported and tend to use resources earmarked for applied research. Given the importance of basic research to private industry output, this diversion of resources could be optimal. The ability of public institutions to do applied research while crowding-in private applied research suggests that public policies such as the Matching Investment Initiative have been successful in mitigating the normal crowding effects. The positive impact that IPRs had on private revenue suggests that these changes have been effective in providing incentives for private research.

The prevalence of non-pecuniary inter-firm research spillovers suggests a strong research clustering effect—an effect that is particularly evident in Saskatoon where there is a significant concentration of public and private firms involved in canola research. The existence of a clustering effect suggests the need for a mechanism for the co-ordination of private and public location choices to maximize the spillover opportunities. The significant public-to-private spillovers emphasize the importance of the public institutions in these clusters.

In this study we found empirical evidence of a variety of research spillovers in the canola research industry. The importance of research to economic growth suggests a need to fully understand these complex non-market relationships, and to manage research policy with these spillovers in mind.
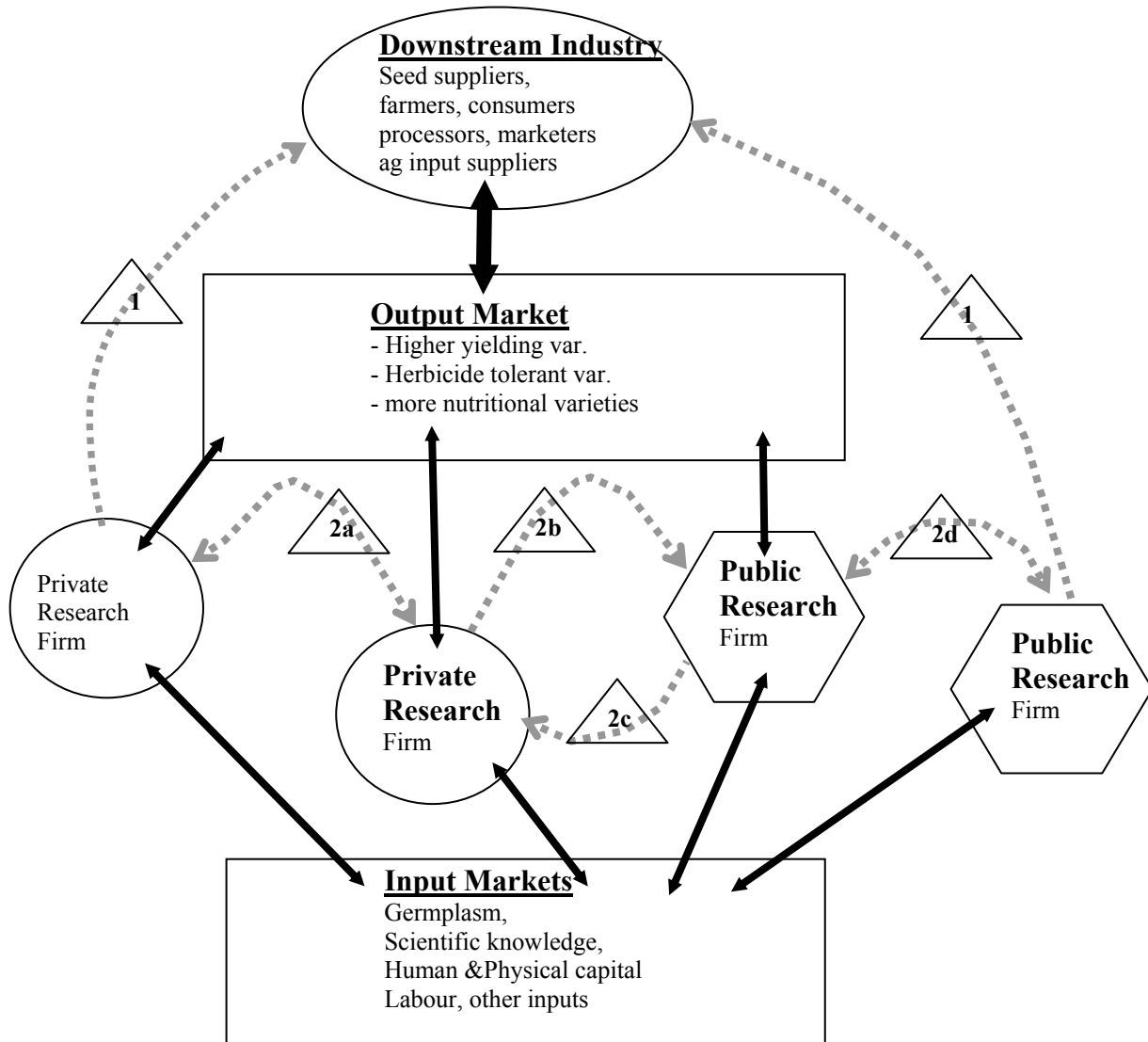
Figure 1: Schematic of Research Spillovers in the Crop Research Industry

Table 1: Regression Results of Model 1

Dependent Variables: Annual weighted yield index of private firms i in year t : $Y_{i,t}^{PV}$ public firms: $Y_{i,t}^{PUB}$

Variable	Acronym		Coefficient	t-Statistic	Prob.
Private applied research expenditures in year t–6	$AR_{i,t-k}^{PV}$	β_1	2.116	8.171	0.000
Basic research expenditures in year t–9	BR_{t-l}	β_2	0.304	3.326	0.001
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
Public applied research expenditures in year t–6	$AR_{j,t-k}^{PUB}$	δ_1	0.601	2.087	0.038
Basic research expenditures in year t–9	BR_{t-l}	δ_2	–0.200	-1.734	0.085
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 firms in year t–7	AR_{t-m}^{PV}	δ_4	–0.163	-2.018	0.045
Total yield index of other-public firms in year t–6	$OY_{j,t-h}^{PUB}$	δ_5	0.036	2.297	0.023
Yield index of private firms at year t–12	Y_{t-g}^{PV}	δ_6	0.000	-0.317	0.752
Yield index of private firm 1 in year t–1	$Y_{1,t-1}^{PV}$	γ_1	0.067	4.221	0.000
Intercept private firm 1	constant	β_{01}	37.665	5.128	0.000
Yield index of private firm 2 in year t–1	$Y_{2,t-1}^{PV}$	γ_2	0.335	3.761	0.000
Intercept private firm 2	constant	β_{02}	54.000	4.927	0.000
Yield index of private firm 3 in year t–1	$Y_{3,t-1}^{PV}$	γ_3	0.479	6.419	0.000
Intercept private firm 3	constant	β_{03}	48.706	4.758	0.000
Yield index of private firm 4 in year t–1	$Y_{4,t-1}^{PV}$	γ_4	0.500	7.431	0.000
Intercept private firm 4	constant	β_{04}	42.836	4.491	0.000
Yield index of private firm 5 in year t–1	$Y_{5,t-1}^{PV}$	γ_5	0.500	6.697	0.000
Intercept private firm 5	constant	β_{05}	47.323	4.712	0.000
Yield index of public firm 1 in year t–1	$Y_{1,t-1}^{PUB}$	γ_6	0.521	5.251	0.000
Intercept public firm 1	constant	δ_{06}	50.287	4.858	0.000
Yield index of public firm 2 in year t–1	$Y_{2,t-1}^{PUB}$	γ_7	0.940	14.495	0.000
Intercept private firm 2	constant	δ_{07}	-0.615	-0.131	0.896

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

Table 2: Regression Results of Model 2

Dependent Variable: Revenue of private firm i in year t: $R_{i,t}^{PV}$ public firm j in year t: $R_{j,t}^{PUB}$

Variable	Acronym		Coefficient	t-Statistic	Prob.
Private applied research expenditures in year t–9	$AR_{i,t-k}^{PV}$	α_1	0.480	1.854	0.065
Basic research expenditures in year t–7	BR_{t-l}	α_2	0.346	2.777	0.006
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
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 Breeders' 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
Public applied research expenditures in year t–9	$AR_{j,t-k}^{PUB}$	θ_2	0.962	3.231	0.002
Basic research expenditures in year t–7	BR_{t-l}	θ_1	–0.187	-0.639	0.524
Total applied research expenditures of other-public firms in year t–9	$OAR_{j,t-r}^{PUB}$	θ_3	–2.412	-4.159	0.000
Total applied research expenditures of private firms in year t–8	AR_{t-m}^{PV}	θ_4	0.278	1.050	0.295
Total yield index of other-public firms in year t–9	$OY_{j,t-h}^{PUB}$	θ_5	0.247	1.816	0.071
Yield index of private firms at year t–12	Y_{t-g}^{PV}	θ_6	0.00022	-2.740	0.007
The proportion of the total area seeded to hybrid (HYB) varieties for public firm at time t	$HYB_{i,t}^{PUB}$	θ_7	–3.996	-0.842	0.401
Plant Breeders' 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	$TUREV_{i,t}^{PUB}$	θ_9	7.738	1.393	0.165
Revenue of private firm 1 in year t–1	$R_{1,t-1}^{PV}$	λ_1	1.199	7.258	0.000
Intercept private firm 1	Constant	α_{01}	24.777	2.377	0.019
Revenue of private firm 2 in year t–1	$R_{2,t-1}^{PV}$	λ_2	0.412	3.763	0.000
Intercept private firm 2	Constant	α_{02}	25.347	2.434	0.016
Revenue of private firm 3 in year t–1	$R_{3,t-1}^{PV}$	λ_3	0.882	14.516	0.000
Intercept private firm 3	Constant	α_{03}	22.105	2.115	0.036
Revenue of private firm 4 in year t–1	$R_{4,t-1}^{PV}$	λ_4	0.497	6.137	0.000
Intercept private firm 4	Constant	α_{04}	25.885	2.492	0.014
Revenue of private firm 5 in year t–1	$R_{5,t-1}^{PV}$	λ_5	0.636	10.483	0.000
Intercept private firm 5	Constant	α_{05}	25.844	2.484	0.014

Table 2: Regression Results of Model 2 (continued)

Dependent Variable: Revenue of private firm i in year t: $R_{i,t}^{PV}$ public firm j in year t: $R_{j,t}^{PUB}$

Variable	Acronym		Coefficient	t-Statistic	Prob.
Revenue of public firm 1 in year t–1	$R_{1,t-1}^{PUB}$	λ_6	0.437	3.428	0.001
Intercept public firm 1	constant	θ_{06}	41.328	4.419	0.000
Revenue of public firm 2 in year t–1	$R_{2,t-1}^{PUB}$	λ_7	0.383	2.714	0.007
Intercept private firm 2	constant	θ_{07}	−16.897	-1.160	0.248

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

Table 3: Regression Results of Model 3

Dependant variables: Social revenue of private firm i in year t: $SR_{i,t}^{PV}$ public firm: $SR_{j,t}^{PUB}$

Variable	Acronym		Coefficient	t-Statistic	Prob.
Private applied research expenditures in year $t–11$	$AR_{i,t-k}^{PV}$	φ_1	1.846	1.730	0.085
Basic research expenditures in year $t–7\,\varphi_1$	BR_{t-l}	φ_2	0.806	2.273	0.024
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
Plant Breeders' Right dummy in year t	PBR_t	φ_5	29.947	5.083	0.000
Public applied research expenditures in year $t–11$	$AR_{j,t-k}^{PUB}$	μ_1	5.236	2.981	0.003
Basic research expenditures in year $t–7$	BR_{t-l}	μ_2	−5.727	-3.173	0.002
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
Plant Breeders' Right dummy in year t	PBR_t	μ_5	−42.473	-1.851	0.066
Social revenue of private firm 1 in year $t–1$	$SR_{1,t-1}^{PV}$	ρ_1	0.764	7.001	0.000
Intercept private firm 1	constant	φ_{01}	−3.569	-0.634	0.527
Social revenue of private firm 2 in year $t–1$	$SR_{2,t-1}^{PV}$	ρ_2	0.221	2.043	0.043
Intercept private firm 2	constant	φ_{02}	−4.157	-1.163	0.246
Social revenue of private firm 3 in year $t–1$	$SR_{3,t-1}^{PV}$	ρ_3	0.726	9.972	0.000
Intercept private firm 3	constant	φ_{03}	0.088	0.013	0.990
Social revenue of private firm 4 in year $t–1$	$SR_{4,t-1}^{PV}$	ρ_4	0.697	9.390	0.000
Intercept private firm 4	constant	φ_{04}	−14.000	-1.286	0.200
Social revenue of private firm 5 in year $t–1$	$SR_{5,t-1}^{PV}$	ρ_5	0.697	8.560	0.000
Intercept private firm 5	constant	φ_{05}	−1.597	-0.292	0.771
Social revenue of public firm 1 in year $t–1$	$SR_{1,t-1}^{PUB}$	ρ_6	0.425	3.377	0.001
Intercept public firm 1	Constant	φ_{06}	210.067	5.205	0.000
Social revenue of private firm 2 in year $t–1$	$SR_{2,t-1}^{PUB}$	ρ_7	0.587	4.642	0.000
Intercept private firm 2	Constant	φ_{07}	62.267	3.526	0.001

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

Source: Authors' regression estimates

Footnotes for the main body

[1]   We were unable to find any data reporting the amount of basic research undertaken by private firms and therefore cannot estimate this effect. Industry experts indicated that this activity was very limited in private firms.

[2]   The input use data was collected in terms of the number of scientist years per firm. This was converted to real dollar terms using the estimated 2003 $/scientist ratio to facilitate easier comparison with the equations estimated in Models 2 and 3.

Appendix A: Data Description

This appendix 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 were 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.

Yield index

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.[i] 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.[ii] 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).[iii]

Variety Classification
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., Roundup Ready®, Clearfield®, Liberty®), which allowed us to classify each canola 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 (PBRs))
        To capture the effect of cultivating herbicide-tolerant (HT) and synthetic/hybrid canola varieties (HYB), a variable was created that show the proportion of the total canola area seeded to varieties that are either HT or hybrids. The 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 (PBRs) was incorporated by creating a PBR dummy variable. This variable takes the value of 0 before the PBR act came into force August 1, 1990 (Canada 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) [iv]; SeCan (2002); Saskatchewan Agriculture and Food (2002); and the authors' estimates based on the above sources.[v]
        The Technical Use Agreement (TUA) fees or their annual rents equivalent were obtained from various issues of Canola Council of Canada, *Economic Analysis: CPC Annual Reports* (2002) and authors' estimates.[vi] 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, Y_t. The social value of the yield increase attributed to firm i is this commercial value multiplied by the

2

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:

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

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

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Footnotes for the Appendix A

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[i] 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.

[ii] 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 centre of the canola-growing region.

[iii] 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).

[iv] 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).

[v] 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.

[vi] Monsanto charges a $15 TUA per-acre fee 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 per-acre equivalents for these varieties are based on 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.