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PART SIX: Public/Private Sector Relationships

27. Gains to Yield Increasing Research in the Evolving Canadian Canola Research Industry

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Chapter 27

Gains to Yield Increasing Research in the Evolving Canadian Canola Research Industry

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Introduction

Canola is a good example of how research and development can improve the comparative advantage of an industry. In the late 1950s rapeseed was very minor crop in Canada that was used to make lubricant. By the 1980s, genetic, agronomic and processing research had transformed rapeseed into canola, a new crop that contained premium edible oil and a protein meal used for livestock feed. In the 1990s canola became the dominant crop in the black soil zone of the prairies, and a large processing industry had been built around it. In the past few years biotechnology has been used to develop transgenic herbicide tolerant varieties and hybrid varieties that have been widely adopted by Canadian producers. Throughout this forty-year period of development, research has been an important catalyst for growth in the industry.

The funding of canola research in Canada has undergone many changes since its inception in the mid-1950s, when Agriculture Canada began a program to improve rapeseed processing methods. Over time research has shifted from a modest public research program to a large research industry dominated by private sector participation. In 1970, 83% of research spending was public investment. Ten years later, the percentage of public versus private research investment was 63% vs. 38% respectively. By 1997 the private sector's share had grown to 80% of the total (Canola Research Survey 1997). This funding shift is evident in the registration of new varieties. Prior to 1973 all varieties were public, while in the 1990-98 period 86% of the varieties were private. (Canola Council of Canada 1998; Nagy and Furtan 1977; and Prairie Pools Inc, 1977-1992). This large shift in emphasis from public to private research is due to the large increase in private sector investment rather than a reduction in public research.

The change in the private funding of research has coincided with a change in the ownership of the property rights for the research and, implicitly, who benefits from the resulting returns to the investment. In 1987, virtually all of the canola varieties were open-pollinated and non-transgenic, and were not protected by Plant Breeder's Rights until 1990. This meant that virtually all of the acreage was grown without a production agreement, giving producers the right to retain production for future seed use and to sell non-registered seed to their neighbors. In contrast, by 1998, over one half of the acreage was planted to herbicide-tolerant (HT) varieties; producers were required to sign a technology agreement or to purchase a specific herbicide. An estimated 30% of the acreage was seeded to hybrid varieties (Canola Council of Canada 1998) and much of the remaining acreage was seeded to varieties with Plant Breeder's Rights. These changes have put plant breeders in a far better position to capture value from genetic innovation.

Previous research has shown very high rates of return for canola research. The evaluation of public investment in canola research and development (R&D) was first published in 1978 by Nagy and Furtan. For the period 1960–1974 they calculated the internal rate of return (IRR) from improved yield research to be 101%. Ulrich, Furtan and Downey (1984) updated the estimates of IRR in canola research for period 1951 to 1982 and calculated the IRR from improved yield research to be 51%. Ulrich and Furtan (1985) incorporated trade effects and found the estimated Canadian IRR from higher yielding varieties to be 50%. Despite the dramatic changes in the industry since 1982, we could not find a more recent comprehensive analysis.

There have also been some recent advances in the estimation of the returns to research that have yet to be applied to canola. Many studies have used econometrics to examine the effect of R&D investment on agricultural productivity (e.g., Thirtle and Bottomley 1988; Pardey and Craig 1989; Leiby and Adams 1991; Huffman and Evenson 1989, 1992, 1993; Chavas and Cox 1992; Alston, and Carter 1994; Evenson 1996). Some of the more recent econometric studies did not impose the shape and length of adoption lag but applied statistically based transformation of the data and generally have found lower rates of return (e.g., Akgungor et al. 1996; Makki, Tweeten and Threan 1996; Myers and Jayne 1996). Alston, Craig and Pardey (1998) also explicitly dealt with the concept of knowledge depreciation, which is not common in the agricultural R&D literature. These new approaches will have relevance for estimating the IRR for canola research.

Given the dramatic changes that have recently occurred in the canola industry, there is a need to reexamine the returns to research in the sector. In particular, has the entrance of private industry, the change in the property rights, the introduction of biotechnologies, and the change role of the public institutions resulted in a change in the benefits created? A contemporary evaluation of the situation will be useful as a guide for further investment decisions in the canola industry. Furthermore, this evaluation methodology may provide insights or raise important questions for emerging biotechnology research in other sectors.

The objective of this paper is to estimate the returns to yield-increasing Canadian canola research over time as means of examining whether the changes in the canola research industry have affected the returns to research. The paper will begin by presenting with a simple economic model to show how changing property rights and government involvement can affect both the level and the return to research. This is followed by a description of the framework used to estimate the returns to research. The econometric model and the data used to estimate the relationship between research expenditure and yield over time is then presented. This is followed by a description of how the estimated parameters are then applied historically to the canola market to estimate the return to research under different scenarios. The paper concludes with a discussion of the results, the implications for policy and the need for further research.

An Economic Model to Examine the Effect to Property Rights and the Return to Research

In the absence of enforceable property rights, many of the products of research can be copied or reproduced. This creates a "public good" market failure resulting in underinvestment in research activities. As shown in Figure 1, in the absence of complete property rights the private marginal benefit (*MBp*) that can be captured from the marketplace is less than the public or social benefits (*MBs*) of the research. A private research firm will equate the marginal cost (*MC*) of doing research with the private demand (or private marginal benefit) for the research and produce a quantity of research *Qp*. At this amount of research the social marginal benefit of research is far greater than the marginal cost of doing research. In this case, the marketplace fails to produce the socially optimal amount of research *Qs*, where the marginal cost of research is equal marginal social benefit. If the government provides a quantity of research *Qg* – *Qp*, this research creates a social benefit equal to the additional area under the social benefit curve while incurring costs equal to the much small area under the marginal cost curve. In this instance there is a high rate of return to public research, which has been found in many empirical studies. This illustration may characterize the situation in canola research until the mid-1980s before the private sector played a major role.

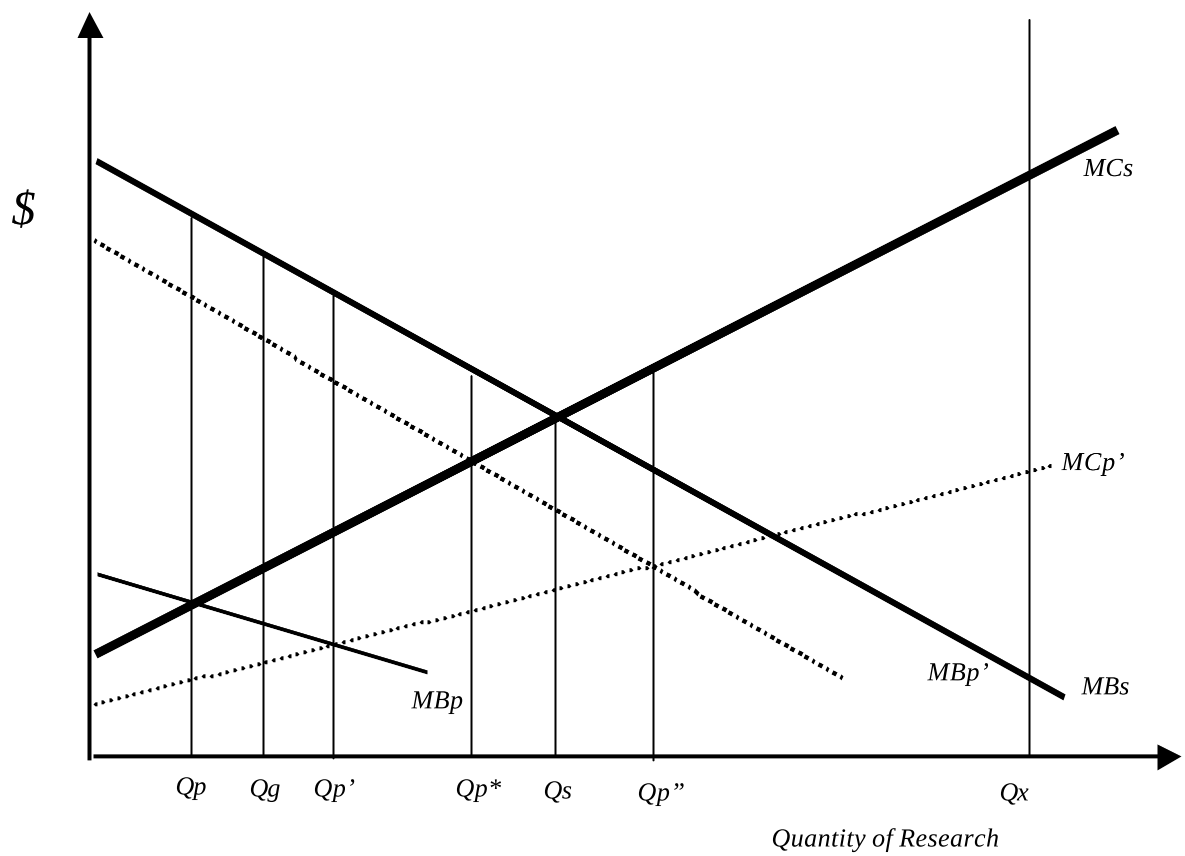

FIGURE 1 The Marginal Private and Social Costs and Benefits of Research

Government has also addressed the incomplete set of property rights for research goods by providing assistance to private firms doing research. This assistance has come in many forms. Research tax credits have been used in many countries and in many sectors to stimulate research. Recently, grants have provided money to match private expenditures on research. Infrastructure has also been provided at a reduced cost in many jurisdictions. Indirect support from the public sector has also come in the form of the public education of research scientists and the free provision of the output of public research. This public assistance to private research has lowered the private cost of doing research, allowing the private sector to do more research. In Canada the public sector has always provided some direct support for private sector research canola. Investment tax credits and infrastructure grants have existed for some time (Phillips, forthcoming). Since 1995 the government has also offered matching investment initiatives (MII), which match private research expenditure in approved projects. This has allowed the private sector to play a greater role in research provision. In Figure 1 this is equivalent to lowering the marginal cost of private research to *MCp'*, which, in the absence of complete property rights, moves the private investment toward the socially optimal level *Qs* to a level of *Qp'*.

Recently, governments, and to some extent the private sector, have addressed the "public good" market failure in research by establishing effective property rights over the products of research. As outlined by Malla, Gray and Philips (1998) the assignment of intellectual property rights provided some of the added ability to capture value from research. The adoption of Plant Breeder's Rights in Canada can forbid the sale of registered varieties without royalty payments. This assignment followed a number of milestones, including the US Patent Office decision of 1985 to grant patents for whole plants. Many of the seeds produced during the 1990s had very specific attributes. Herbicide-tolerant canola requires the use of a specific herbicide in order to be useful. Similarly, canola with particular oil characteristics needed specialized processing and marketing in order to be viable. The development of hybrid varieties has given private firms a greater ability to capture value from their genetic material. The first hybrid variety was introduced in 1989. These varieties, although often protected with Plant Breeder's Rights and production contracts, do not require the enforcement of contracts to maintain control over the use of the genetics.

The establishment of enforceable property rights has the effect of moving the private marginal benefit (market demand) curve toward the social demand curve. As was discussed earlier, this has had the effect of increasing the demand for private research and the amount of private research provided by the private sector, thus partially addressing the market failure. In the absence of government support for research this moves the private investment from *Qp* to *Qp"* in Figure 1. The establishment of property rights changes the optimal role for government. If government provides support for private research, once property rights are established this further increases the private incentive to do research. If the property rights are nearly complete and research support is significant the private sector can provide more research than is socially desirable, as represented by point *Qp** in Figure 1. Thus, both correcting the public good failure and subsidizing research can result in excessive research.

A few final points apparent in Figure 1 are worthy of note. The highest benefit-to-cost ratio, which will generate the highest IRR, will be at some level of research less than the social optimum. The socially optimal quantity research occurs where the marginal social benefit is equal to the marginal social cost. At this point total net benefits of research are maximized. Additional research beyond this point is socially wasteful, costing more on the margin than what is produced. At these excessive levels of research (anything less than the *Qx* in Figure 1) the total benefits can still be greater than total costs, and the IRR can still be above market rates. Importantly, a positive overall return to research, or an IRR greater than market rates, does not imply that more research is socially desirable – rather, it suggests that the research program taken as whole has produced net benefits.

This simple economic model presented in Figure 1 illustrates several important concepts for research policy. The first is that in the absence of enforceable property rights, the private sector will underinvest in research, creating a role for government to address the research shortage. Second, the assignment of property rights to research products can increase the amount of private investment toward the socially optimal amount. Third, if enforceable property rights have been established the subsidization of private research could lead to socially wasteful overinvestment in research. Finally, an assessment of total research benefits or the rate of return on total investment are not good indicators that on the margin more research is socially desirable.

Estimating the Returns to Agricultural Research

This section contains a brief description of the conceptual framework used to estimate the returns to canola research.[2] The process of creating new crop varieties can be described in four phases, as shown in Figure 2. The first phase is the research phase, which involves effort over a number of years to create varieties with commercially desirable genetic traits. The second phase is the gestation phase, which is the period when potential varieties undergo private and public testing and multiplication, preparing the variety for potential registration and commercial sale. In the adoption phase, after commercial release of the variety, the varieties are adopted and grown by producers, contributing to increased productivity. In the fourth phase, these new varieties become part of the germplasm and knowledge stock from which newer varieties are created. This fourth phase continues even after the particular variety is no longer grown. Over time the contribution to the knowledge stock depreciates as pests adapt themselves to the germplasm and new techniques replace older ones (Alston, Craig and Pardey, 1998). These four phase phases of crop variety development, and the long lags between investment and output, have made the estimation of returns to research difficult and a subject of considerable debate.

Estimating the Relationship between Expenditure and Yield Increase

The empirical procedure began by constructing a yield index of different canola varieties to the same base variety (Torch=100). The annual yield index was created from

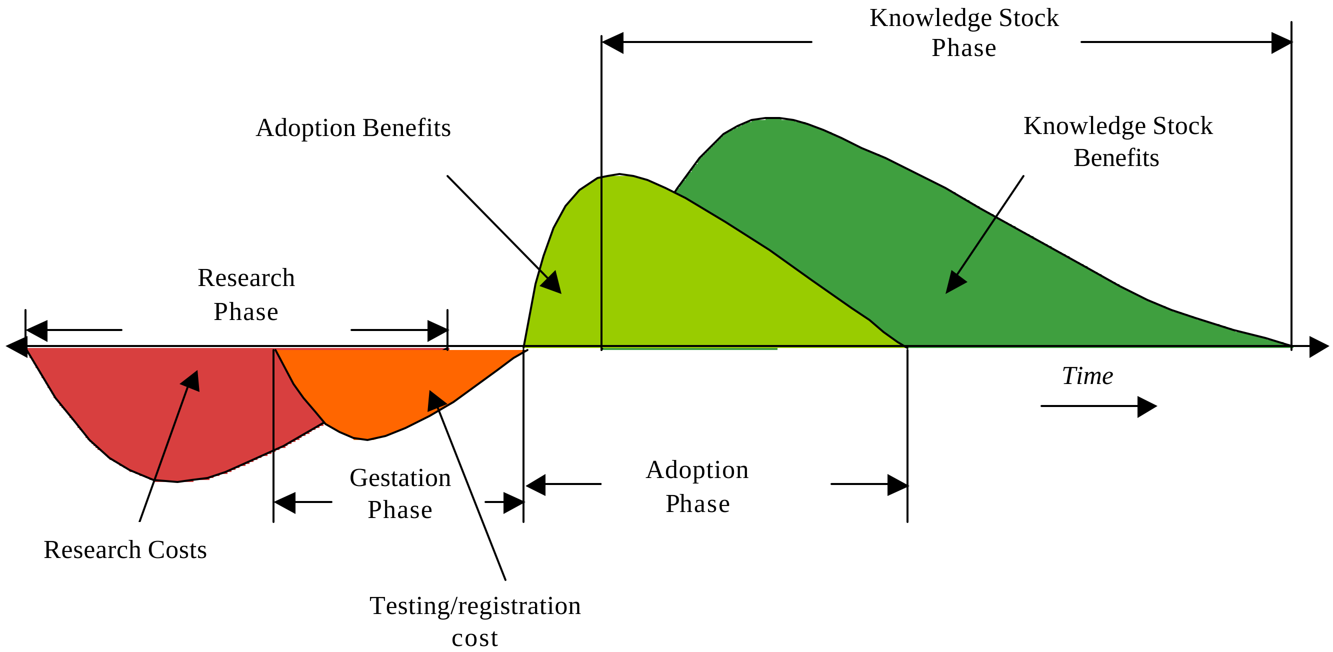

FIGURE 2 Four Phases of Crop Development and the Path for R&D Cost and Benefits

an average of the yield index for varieties grown each year, weighted by the seeded acreage. The data, on the relative yield of different varieties, were obtained from various issues of Saskatchewan Agriculture and Food, Varieties of Grain Crops in Saskatchewan. This data is based on the research station yield trials at a number of locations across Saskatchewan, which were designed to measure varietal performance due to genetic causes. The data on the percentage acreage of each canola variety were obtained from three sources. The first source was a 1987 study by Nagy and Furtan, which covered the period 1960 to 1976. The second source was collected from various issues of Prairie Pools Inc., Prairies Grain Variety Survey (1977-1992). The final source was the authors' estimates based on the Manitoba Crop Insurance Corporation Variety Survey. The annual yield in index since 1960 is shown in Figure 3.

In addition to the genetic stock there are two other factors that will influence the yield index of the varieties grown. First of all there are two types of rapeseed/canola grown that are grown in Canada: Argentine species (Brassica napus L) and Polish species (Brassica rapa L). Argentine varieties are higher yielding than Polish varieties (15% to 20%) while Polish varieties mature faster. The proportion of area grown to each will vary from year to year, with more Polish varieties seeded when spring is late. In order to capture the effect of planting Argentine versus Polish varieties a variable indicating the proportion of area seeded to Argentine varieties is included in the regression. The other yield factor that needs to be accounted for is the switch from rapeseed to canola varieties. The selection for low erucic acid and glycosynilate in canola quality has been attained at the expense of seed yield. Figure 3 reveals the reduction in the annual weighed average yield index yield from 1978 to 1984 when the changeover was made. This result is similar to other findings, which have shown that the combined yield of Argentine and Polish type canola varieties decreased from the middle 1970s to the beginning of the 1980s (e.g., Forhan 1993, Malla 1997). To account for the yield effect of the conversion of rapeseed to canola, a variable was created that represents the percentage of total rapeseed/canola varieties seeded that were canola varieties. This variable is also included in the regression.

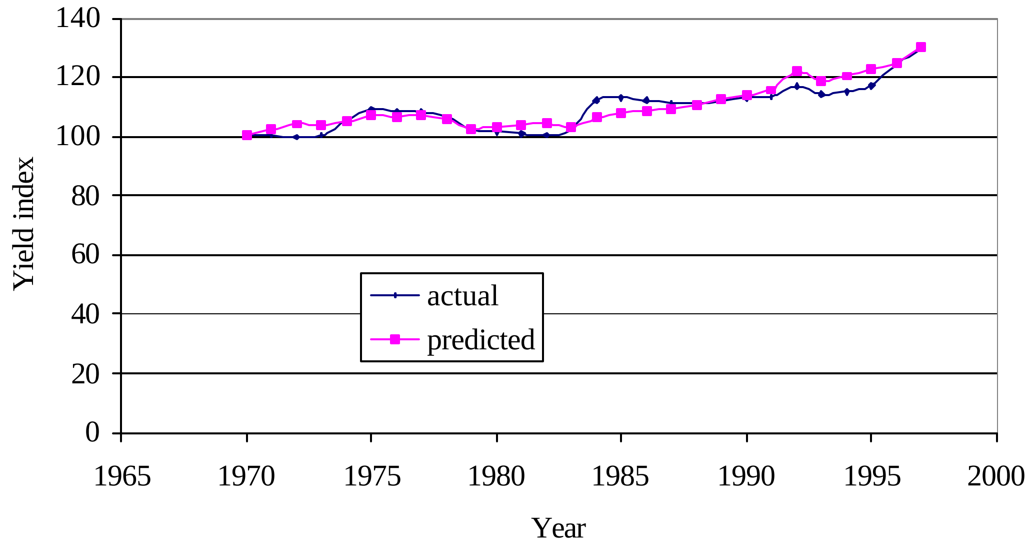

FIGURE 3 Actual Versus Predicted Yield Index Change

The total research expenditure per year was calculated by multiplying the total person-years invested in the research by the total research cost, fixed and variable (Canola Research Survey 1997-1998), for each year. A person-year is used to define either a professional person-year and a technical person-year, where a professional person-year corresponds to full-time annual work dedicated to professional research and a technical person-year corresponds to full-time annual work on technical research (as reported in the Inventory of Canadian Agri-Food Research). The data on canola research professional and technical person-years were obtained from four sources: Canola Research Survey 1997–1998; Nagy and Furtan (1977); ISI (Institute for Scientific Investigation); ICAR (Inventory of Canadian Agri-Food Research); and Phillips (1997). Where there were discrepancies in the overlapping periods from the data source, the earlier estimates were indexed upward to reflect later estimates.[3]

An average adoption curve for canola varieties was estimated rather than assuming a specific adoption lag structure. The individual adoption rate of each rapeseed/

canola variety was calculated by dividing the acreage sown of each variety by the maximum acreage sown of that variety for each year after the year of introduction. These adoption rates were then averaged for all varieties and weighted to sum to one. The average adoption curve is reported in Figure 4.

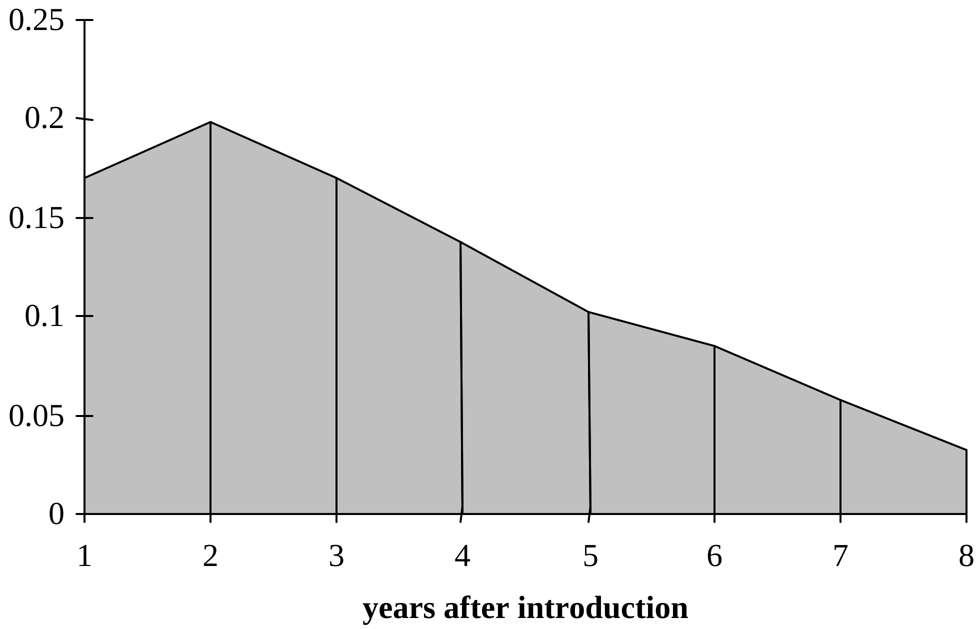

FIGURE 4 Average Adoption Curve For New Canola Varieties

The weighted average adoption rate of rapeseed/canola varieties was applied to the cost data to create a variable of the weighted lag research expenditure. The adoption curve means that on average the acreage planted today to specific varieties is a function of when in the past the varieties were introduced. The annual weighted yield index is therefore an average of the yield of varieties previously introduced weighted by the respective coefficients on the adoption curve. Mathematically,

(1) $$Y_t = \sum_{i=1}^{n} g_i y_{t-i}$$

where Y_t is the yield index in year t , $\tilde{a}_i$ is the weights on the adoption curve, and y_{t-i} is the average reported yields of the varieties introduced in year t–i. Given this relationship it follows that the annual change in the weighted yield index is a weighted average of the changes in the yield of the varieties introduced, or:

(2) $$dY_t = \sum_{i=1}^{n} g_i dy_{t-i},$$

where *dY* and *dy* represent the change in the weighted index and the yield of new varieties. If change in new variety yield is proportional to the lagged expenditures on research, or $dy_t = rX_{t-g}$, where X_{t-g} is the expenditures in year t–g, and g is the gestation lag, then:

(3) $$dY_t = r\sum_{i=1}^{n} g_i X_{t-i-g} \; .$$

Making these assumptions, the change in the annual weighted yield index is proportional to the adoption curve weighted yield expenditures.

To estimate the effect of a research expenditure on the average yield index we specified and estimated the following regression.

(4) $$dY_t = b_R \log X_{t-g} + b_C\, dDCAN_t + b_A\, dDARG_t + \text{å}$$

where

dY_t is a change in the annual weighted average yield index for a year t,

X_{t-g} is the annual adoption lag weighted research expenditure for a year t minus the gestation lag (a number of years between making an investment and beginning to have an effect on yield index),

$DCAN_t$ is a change in a percentage of the total canola/rapeseed varieties that are canola varieties, which takes a value between 0 and 1, and

$DARG_t$ is a change in a percentage of the total canola/rapeseed varieties that are Argentine (b. napus) varieties, which takes a value between 0 and 1.

In order to determine the appropriate specification of the model, the time-series properties of the variables in the model were examined. In the research expenditure series the Dickey-Fuller test and Phillips-Perron test revealed that a unit root could not be rejected in favor of a stationary when it is measured “in level.” However, when the research expenditure is measured in logarithm, the unit root hypothesis is rejected in favor of stationarity. Hence, the logarithms of research expenditure were used in this analysis. For the yield index series, the unit root hypothesis could not be rejected in either the “in level” or the logarithmic form. By taking the first difference of the yield index, the variable is judged to be stationary about a linear trend. Thus, the analysis uses the first difference form. The specification error test was used to determine the adequacy and final specification of the models. The error test was performed using the Ramsey’s Regression Specification Test (RESET).[4]

The regression results are reported in Table 1 and Table 2. Table 1 is the regression results using a four-year gestation lag between research expenditure and the release of a new variety. This four-year gestation lag was inferior only to a one-year lag using the Akaike information criterion. However, the one-year gestation lag regression results reported in Table 2 are very close to the four-year gestation lag results.[5]

TABLE 1 Regression Results for Gestation Lag of Four Years

Dependent Variable: dY		
Independent Variables	**Coefficient**	**T-Statistic***
$\log X_{t-4}$	0.425	2.760
DCAN	-17.095	-2.351
DARG	17.868	3.830
R^2 =	0.466	
Akaike info criterion:	1.771	
(n = 27)**		
Ramsey's Reset Test		
F–Statistic	0.186	Probability-values: 0.671
Likelihood Ratio Test	0.217	Probability-values: 0.641

*The estimated coefficients are significant within a 95% confidence interval.
**R^2 is the coefficient of determination; n is the number of observations.

Source: Authors' regression estimates.

TABLE 2 Regression Results for Gestation Lag of One Year

Dependent Variable: dY		
Independent Variables	**Coefficient**	**T-Statistic***
$\text{Log}X_{t-1}$	0.410	3.096
DDCAN	-17.407	-2.537
DDARG	17.638	4.046
R^2 =	0.464	
Akaike info criterion:	1.655	
(n = 30)**		
Ramsey's Reset Test		
F–Statistic	0.267	Probability-values: 0.610
Likelihood Ratio Test	0.307	Probability-values: 0.580

*The estimated coefficient are significant within a 95% confidence interval.
**R^2 is the coefficient of determination; n is the number of observations.

Source: Authors' regression estimates.

The results appear to be robust, having passed the specification tests and given that the explanatory variables are statistically significant at 5% level, and that the coefficients have the expected signs.[6] The R^2 showed that the explanatory variables explain just less than half of the variation of the year-to-year change in yield. The predicted line in Figure 3 represents the fitted values from the regression estimate.

The coefficient on the Argentine variable in Table 1 indicates that a complete switch from Polish to Argentine varieties would increase yield by 17.86 index points. Similarly, the complete switch from rapeseed to canola varieties reduced the average yield by 17.09 index points. These large effects and may have implications for the value of non-yield traits in canola.

The coefficient of the research expenditure is .425 which means, holding all other variables constant, that a 1% increase in the annual lag weighted research expenditure in year (t-4) increases the yield index level by .00425 index points (Table 1). Given that the yield index was 127 in 1997, a 1% increase in the annual lag weighted research expenditure in year (t-4) increases, on average, the yield index by approximately 0.0033% at 1997 yields.

Net Returns to Canola Research

To calculate the social return from the yield-increasing research the econometric estimates of the yield increase due to research expenditure are applied to the historical production of canola. The regression results reported in Table 1 are used to predict the amount of yield increase due to research expenditure in each year. As an approximation, it is assumed that the additional yield due to genetic improvement came at no resource cost and thus benefits are in direct proportion to revenue each year.[7] Benefits in 1997 dollars are estimated by multiplying the quantity of canola seed (production) to the price of canola seed, and deflating by the consumer price index.[8] The present values of research benefits are estimated by first calculating all future yield increases due to the yield increases in a particular year. This uses the notion that there is a stock of knowledge that is subsequently built upon. This calculation was made using various rates of depreciation. These future yield increases are then applied to the revenue in each future year to calculate the future benefits. For 1997 and beyond it was assumed that 1997 revenue would continue indefinitely. Once the future stream of benefits is calculated this is then brought back to the present value in the year of introduction using a discount rate. The present value of costs for varieties grown in year t is calculated from the present value in year t, of the weighted expenditures lagged by the gestation period and the adoption curve. The Net Present Value (NPV) of research is calculated from the difference between the present value of the benefits and the cost of the research using a number of depreciation and real discount rates.

The NPV results are reported in Table 3. What is most striking is that for each of the scenarios the NPV peaks in the 1980s and declines thereafter. For instance, with 5% depreciation and a 6% real discount rate, the increase in the research expenditures resulted in an increase in net present value from $41 million in 1971 to a peak of $88 million in 1983 which then began to decline as the increase in expenditures exceeded the growth in benefits. By 1997 the net present value of yield increases had declined to $25 million.

TABLE 3 Net Present Value Under Different Scenarios

Scenario	A	B	C	D	E	F
Depreciation	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**	**0.05**
Real discount rate	**0.03**	**0.03**	**0.06**	**0.06**	**0.09**	**0.09**
YEAR of Yield Change						
	Net present Value (Millions of 1997 dollars)					
1971	66.8	44.8	63.2	41.8	59.4	38.6
1972	71.2	48.2	67.1	44.8	62.9	41.2
1973	76.7	52.5	72.2	48.7	67.4	44.6
1974	80.4	55.1	75.3	50.7	69.9	46.0
1975	85.7	58.1	79.9	53.1	73.8	47.7
1976	92.3	61.6	85.9	56.1	79.0	50.0
1977	101.2	68.0	94.2	62.0	86.8	55.4
1978	104.4	69.7	97.1	63.3	89.2	56.3
1979	103.0	66.3	95.3	59.6	86.9	52.1
1980	295.4	107.8	198.0	86.8	153.7	71.0
1981	294.4	107.5	194.6	85.3	149.2	68.6
1982	297.4	110.2	194.6	86.6	147.7	69.0
1983	300.5	113.0	194.4	87.8	146.0	69.1
1984	302.3	112.8	191.8	85.8	141.4	65.8
1985	302.7	111.7	187.7	82.5	135.2	61.0
1986	304.5	112.7	185.2	81.3	130.5	58.2
1987	306.4	115.0	183.4	81.5	126.7	56.9
1988	305.1	115.7	179.1	80.3	121.0	54.2
1989	302.1	114.3	172.8	76.7	113.0	49.0
1990	303.6	116.4	169.9	76.0	107.8	46.4
1991	305.0	118.9	167.0	75.8	102.7	44.2
1992	305.5	120.6	162.8	74.4	96.1	40.6
1993	305.9	122.6	158.5	73.3	89.5	37.2
1994	300.0	118.0	147.5	65.1	75.8	26.6
1995	288.7	107.6	130.4	50.7	55.5	9.3
1996	277.6	97.5	113.2	36.2	35.0	-8.6
1997	268.9	90.8	99.1	25.1	17.8	-22.9

Source: Author's calculation.

TABLE 4 Estimated Internal Rate of Return for Yield Increase (1967-1993)

Lag Depreciation	4 yr. 0%	4 yr. 1%	4 yr. 5%	4 yr. 10%	1 yr. 5%
Year of Yield Change			Internal Rate of Return		
1971	0.398	0.382	0.324	0.260	0.471
1972	0.384	0.369	0.313	0.252	0.442
1973	0.371	0.356	0.303	0.245	0.425
1974	0.350	0.336	0.285	0.228	0.404
1975	0.336	0.322	0.271	0.215	0.389
1976	0.328	0.313	0.261	0.205	0.375
1977	0.327	0.312	0.261	0.208	0.380
1978	0.318	0.304	0.253	0.201	0.375
1979	0.304	0.289	0.236	0.180	0.355
1980	0.366	0.343	0.262	0.182	0.397
1981	0.353	0.331	0.253	0.174	0.380
1982	0.344	0.323	0.248	0.172	0.369
1983	0.333	0.314	0.243	0.170	0.359
1984	0.319	0.301	0.232	0.159	0.338
1985	0.304	0.286	0.218	0.145	0.315
1986	0.290	0.272	0.208	0.137	0.299
1987	0.276	0.260	0.200	0.134	0.289
1988	0.263	0.248	0.192	0.130	0.275
1989	0.247	0.233	0.181	0.121	0.256
1990	0.235	0.222	0.173	0.118	0.244
1991	0.223	0.211	0.167	0.117	0.231
1992	0.210	0.199	0.159	0.113	0.213
1993	0.198	0.188	0.153	0.112	0.197
1994	0.179	0.170	0.137	0.100	0.171
1995	0.152	0.145	0.114	0.079	0.136
1996	0.126	0.119	0.092	0.060	0.102
1997	0.105	0.099	0.075	0.047	0.076

Source : Calculated from Regression Estimates.

Table 4 shows the estimated IRR for the change in yield increases for the year 1970-1997, under different assumptions about deprecation rates and lag structures. The first four columns show the IRR from the regression results from Table 1, with a four-year gestation lag and 0%, 1%, 5% and 10% depreciation rates respectively. Not surprisingly, the IRR declines as the deprecation rate increases because the investment is not a durable. The last column of Table 4 shows the IRR with a one-year gestation period. As expected, this increases the IRR and illustrates once again that the IRR can be sensitive to assumptions about the gestation lag. What is most striking in this table is general the decline in the IRR as the level of investment has increased. While the IRR was clearly excessive in the early 1970s they had declined to market levels by the mid-1990s.

Given that many biotechnologies became predominant during the 1980s the declining NPV and IRR provides little support to the notion that biotech has led to significant increases in the returns to research. However, in 1997 about 35% of area was sown to herbicide tolerant varieties and thus the research may have produced other benefits not measured as a yield increase. Yet, given the very recent introduction of herbicide tolerant varieties, this phenomena does not explain the decline in the NPV prior to 1996.

The increase in the level of expenditures and the declining IRR approaching market rates suggests that the assignment of property rights and matching grants has corrected the public good market failure. Further extrapolation of these rates of return would suggest an over investment in the sector resulting in low private and social IRR for investment. The decline in the NPV of research as expenditure increases is consistent with the moving beyond the optimal amount of research.

Figure 5 shows the IRR with 1% and 5% depreciation rates. One interesting feature of these series is the increase in the rate of return, in the late 1970s when canola acreage surged in response to growing on farm wheat stocks brought about by grain transportation constraints. Note however, revenue during the mid-1990s was near record levels, and despite this, the rate of return is low.

Conclusions

The objective of this study was to examine the returns to research for investment in the canola sector in Canada for the period 1960-1997. Many changes took place in the industry during this period. A small but very successful public research program eventually became dominated by a large influx of private research investment induced by property rights and technologies that provided a greater opportunity for capture the benefits from research. During private growth period the technologies used for genetic improvement shifted from traditional breeding to the use of many biotechnologies. This study focused on the net social benefit from yield increasing canola research.

The rate of return from canola research has been on the decline throughout the study period. Specifically, the IRR from the high rate era of the 1960s and 1970s has declined and become more realistic in the 1990s. Moreover, the total net present value of yield increasing research peaked some time during the early 1980s and has subsequently declined -- suggesting an overinvestment in research. This result indicates that the increase in private research and development efforts did not actually yield as much net benefit as one would expect when witnessing a large amount of private investment flowing into an otherwise public funded research area. Therefore, further investment in canola research and development may not be as profitable a venture as the investment stampede would lead us to believe.

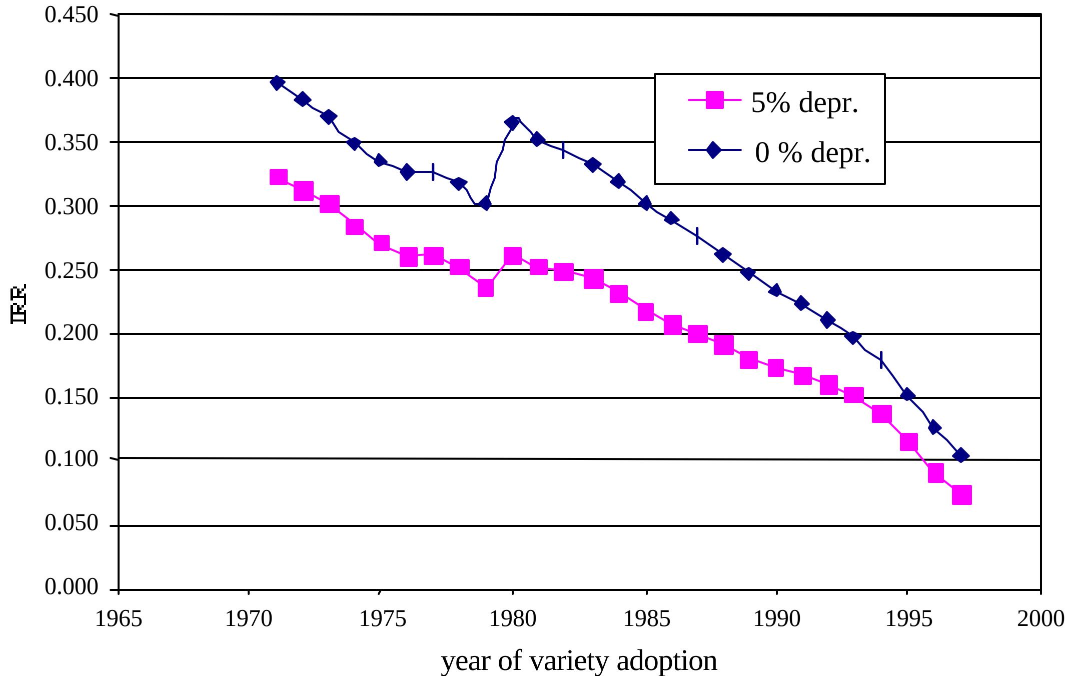

FIGURE 5 Estimated IRR for Canola Yield Increasing Research (1967-1993)

This study challenges the current government policy in canola research. The canola research industry is heavily subsidized and property rights for canola seed are well established. Given property rights allow private firms to capture the full social benefit of investment this will attract capital and drive the rate of return toward normal levels. If government on top of that subsidizes the costs of private research, then it is certainly possible to create over investment an industry. The analysis presented shows declining net present value of investment. Consequently the industry might already be operating beyond the point where the marginal benefit is equal to the marginal cost. Hence, this study indicates a need for a much closer examination of policy in this industry.

The general result that biotechnology has yet to produce measurable high social returns in the canola sector raises some very important questions. Clearly, genetic traits other than yield have economic value, would the incorporation of these effects change the general conclusion? If the net present value has fallen, does the vintage of a crop, to a large extent, dictate the rate of return to research? Is there a natural cycle to crop development, which has an increasing and then a decreasing return to research investment? If this is true, then should public investment be targeted to crops on the basis of vintage rather than historic rates of return? A related question is; what has been happening to the rate of the return in other crops and in other sectors? Of particular importance is whether the falling rate of return in canola is the result of the assignment of

IPR's that have become general to all crops, or do market failures continue exist in other crops where hybrids and other physical reproductive barriers do not exist? Answering these will provide some important insights to the best policies to govern the rapidly expanding biotechnology industry.

Endnotes

[1]Paper prepared for the ICABR conference on "The Shape of the Coming, Agricultural Biotechnology Transformation: Strategic Investment and Policy Approaches from an Economic Perspective." University of Rome "Tor Vergata," June 17-18-19, 1999. Please email comments to gray@duke.usask.ca.

[2]A conceptual model for measuring these returns and many of the empirical issues that have to dealt with are explained in some detail in the book entitled *Science Under Scarcity* by Alston, Norton and Pardey, 1997.

[3]For more details on the data source and the calculation see Gray, Malla, and Phillips (forthcoming).

[4]The Ramsey's RESET test adds extra regressors to the original regression and examines the hypothesis that the coefficients on the forecast vectors are all zero. The null hypothesis is rejected whenever the associated probabilities of the output from the test (F-statistic and likelihood ratio test) were less than 0.05, which indicate evidence of specification error.

[5]We use the results in Table 1 for the calculation of the rate of return because of prior information that suggests that it takes several years of research and testing to develop and introduce a new variety.

[6]A squared log expenditure term was added to the regression to create a more flexible fit but was rejected as the adjusted R squared decreased.

[7]This is consistent with the treatment in the research plots where additional yield is measured with no additional use of crop inputs. There would be additional costs for harvesting and transport to the elevator which are small per tonne an not accounted for in our analysis.

[8]The price of canola seed in Canada was obtained from Saskatchewan Agriculture and Food, Agricultural Statistics 1997. The price of canola seed was the Saskatchewan farm price in Canadian dollars per metric tone. The data for the consumer price index (CPI) was obtained from Statistics Canada, Direct Cansim Time Series: CPI and All Goods for Canada (1998). Finally, the quantity of canola production was obtained from Statistics Canada, Direct Cansim Time Series: Canola-Rapeseed/production, metric tonnes, canola-Canada, (1998).

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