BIOTECHNOLOGY AND RETURNS TO AGRICULTURAL RESEARCH:A CASE STUDY ON PLANT BREEDING IN CANADA

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I. Introduction

Biotechnology has been part of the economics literature since Reverend Thomas Malthus (1798)observed there was a natural tendency of the population to grow faster than the food supply. Malthus was not alone in his thoughts. Ricardo (1817) supported Malthus' fears with the thesis on the law of diminishing returns. Both were dubbed the "professors of the dismal science". Galbraith (1958) observed that the title has stuck with economics into the twentieth century even though biotechnology has dimmed the Malthusian specter.

While neoclassical theory retains the assumptions of limited resources, unlimited wants and constant technology, the economic literature frequently address the implications of changing technology. Agricultural economics is no different. Food and fibre supply, and the effects that changes in technology has upon market equilibria is prevalent in the agricultural economics literature. By its nature food and fibre production involves biotechnology and the agricultural economics literature should gain greater prominence now that biotechnology is receiving more attention through genetic engineering.

The purpose of this paper is not to review the many papers written on the subject as this would retrace ground already covered by Peterson and Hayami (1977) and Norton and Davis (1981). Instead a brief overview of how the concept of economic surplus has been applied to evaluate the welfare effects of agricultural research will be covered. This is followed by a presentation of a study on the returns to plant breeding research on cereal grains and oilseeds production in western Canada. Lastly some observations are provided with respect to evaluating returns to innovations in biotechnology.

II. Economic Surplus and Returns to Technological Innovation

The conceptual flexibility of economic surplus has allowed agricultural economists to span a multitude of commodities when studied one at a time. The focus was primarily upon a technological innovation which lowered production costs and shifted the supply curve. The basic type of model is given in Figure 1 where the market equilibrium prior to innovation is P_0

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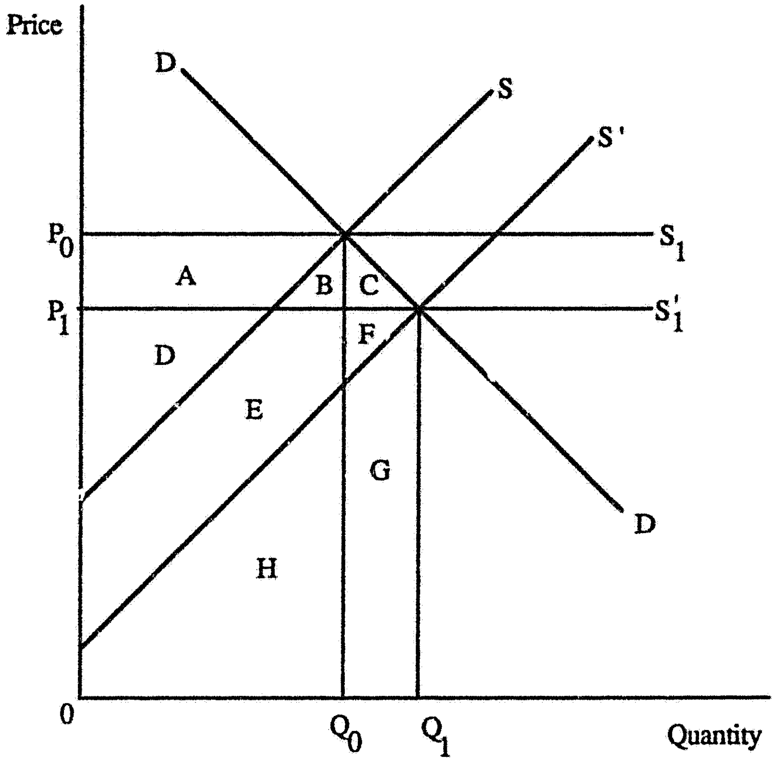


Fig. 1: Effects of a supply shift resulting from technological change

(Source: Currie, Murphy and Schmitz 1971) and Q_o. Shifting supply from S to S^1 results in a net social gain of B + C + E + F where the change in producer surplus is (E + F) - A and consumer surplus increases by A + B + C.

Lindner and Jarrett (1978) focused the debate on measuring the net social gain caused by a cost induced shift in supply to estimating

(a) the size of the shift at the without innovation equilibrium level of output, Q_o;

(b) the type of supply shift in terms of whether the cost reduction twists or merely shifts the post innovation supply curve; and

(c) the expanded level of output (Q_1) induced by the innovation.

The size of the shift is a major determinant of the net social gain. Hertford and Schmitz (1977) measured the shift in terms of an output effect (horizontal shift in the supply curve) while Lindner and Jarrett (1978) and Rose (1980) viewed it as a cost reduction and a vertical curve shifter. Area E + B in Figure 1 is the largest component of net social gain and depends solely upon the supply shift and the equilibrium level of commodity traded prior to the innovation. The relative magnitude of E + B in comparison with the net social gain of E + B + C + F with an demand curve DD or area A + B in comparison with A + B + C when supply is assumed to be perfectly elastic, indicates the quantitative importance of measuring the size of the shift.

The relative importance of the equilibrium levels (Q_o) and (P_o) prior to the innovation in comparison with the change in quantity (Q_1 - Q_o) would suggest that biotechnological research will have the greater payoff by focusing upon commodities with larger total revenue. Furthermore a relatively smaller cost savings is required when the quantity produced is relatively greater. Assuming two commodities have equal total revenue then the economic framework would suggest a relatively smaller reduction in cost is required for the commodity with the greater output. The implications are that research should be focused upon commodities with relatively larger levels of output because the cost savings is spread over more product. Specialisation would lead to more specialisation as research focused on improving the technology of the more dominant product. This assumes equal likelihood that research will reduce the costs of production for either commodity.

The bias of the economic surplus framework toward initial price and quantity equilibrium is based upon the price elasticity of supply and demand. The net social gain from the additional output (Q_1 - Q_o) relative to the initial level Q_o diminishes as elasticity declines. After determining the sensitivity of the net social gain to a range of elasticities Rose (1980) concluded that it had little influence upon the size of the net social gain. Hertford and Schmitz (1977, p. 155) also reached similar conclusions and stated "the critical determinant of the value of the net social gain is simply the percentage change in the value of production attributable to research".

Supply and demand price elasticities are however critical determinants in the distribution of the net social gain between consumers and producers. If the relative price elasticity of supply exceeds demand consumers capture more of the net social gain. Area ABC in Figure 1 represents the net social gain when a perfectly elastic supply curve P_0S_1 shifts to $P_1S_1^1$ and the total gain is realised by consumers. Whereas, the net social payoff is not overly sensitive to price elasticities their importance is in terms of establishing how the net social payoff is shared by producers and consumers.

The nature of the shift in the supply curve is important in empirically measuring the net social payoff from a research induced innovation [Lindner and Jarrett, 1978]. Rose (1980) however, suggests the nature of the shifts is difficult to determine because supply curves for individual commodities include the shadow prices of fixed factors of production when the fixed factor can be used by more than one commodity. Cropland is virtually fixed in total but it is not fixed in terms of how it is allocated to produce two or more crops. The supply curve for each individual commodity is a function of the prices of the variable factors of production and the shadow prices of the fixed factors The shadow prices are in turn determined by the prices of the alternative crops and the incremental increase in output derived from shifting more of the fixed factor to produce the alternate commodity. Therefore the supply curve is not the marginal cost exclusive of rents. When the curve is shifted to account for a cost reducing technology it must be recognized that the cost reduction only applies to a portion of the curve related to the variable factors. Furthermore, the technological change will also likely change the relative marginal productivity of the fixed variable factors to produce the commodity affected by the research. Only a neutral technological change will shift a function the more likely case is a shift and twist. These parameters can only be found by further study of the technological relationships underlying the industry costs before and after the change.

A shift and twist in the supply function also requires that the derived demand functions of inputs used in the production of the commodity in question to do the same. Schmitz and Seckler (1970) shifted the derival demand for farm labor as a result of mechanisation to show the displacement of labor. The unemployment implications of less than perfectly mobile labor reduced the net economic benefit. Besides the derival demand for inputs shifting from the technological impact upon the elasticity of substitution between inputs, the demand functions will also shift if equilibrium prices for the commodity drop following the innovation. The equilibria in the input markets must be derived concurrently with the changes in the commodity market so the resultant supply function is characterised correctly. Most agricultural economics studies have assumed the changes in input markets to be inconsequential to the evaluation in terms of perfect factor mobility. Measurement errors were then confined to the shift in the supply. Little attention has been given to the twist even though it has significant implications for the magnitude of the net economic benefit and the factor markets.

The aversion to probe beyond the partial equilibrium commodity specific evaluation was noted by Norton and Davis (1981) as an area requiring further methodological work. Evaluations of biotechnological innovations which simultaneously affect more than one commodity have virtually been ignored. Developments such as biological disease control, pesticides, plant growth stimulants or even improved fertility through placement and release of plant nutrients can not be evaluated in a single commodity framework. Genetics research in terms of improved crop varieties and livestock breeds fit well within the commodity exclusive framework. Research on genetic engineering techniques, like basic research, has applicability across many commodities. The evaluation framework must be expanded from one to many commodities and from excluding the factor markets to encorporating them. Only then will the returns to biotechnology research be evaluated fully and the implications on the distribution of the gains to the resources employed in the industry be fully understood.

III. Plant Breeding and the Cereal Grain Economy of Western Canada

Cereal grains and oilseeds account for two thirds of the value of agricultural production in the prairie provinces of Manitoba, Saskatchewan Alberta. Between 1978 and 1988 the value of these crops ranged from $c4 billion to $c8 billion. The extreme variation in the annual crop value is primarily related to; droughts in 1980, 1984 and 1988; record production levels in 1981, 1982 and 1986; record high prices in 1980 and 1981 and twenty year low prices in 1986 and 1987. Underlying the economic and weather shocks has been a steady upward trend in crop production. Over the past 25 years, total cereal grain and oilseed production has increased at an annual average of 2 per cent. [Kraft, 1980.]

A. Land Related Increases in Production

In the span of 25 years (1961-1986) the area seeded has increased from 15 million hectares to 23.6 million hectares. About half of the increase in seeded area has taken place in the last ten years. While the area in crop increased 1.3 per cent annually, the yearly contribution of land to total production was about 0.4 per cent. Nearly all the additional area occurred because less land was summerfallowed. Stubble yields are lower than fallow yields and without additional expenditures on fertilisers and pesticides the total increase in output only ranges between 0.3 per cent to 0.4 per cent for a 1 per cent increase in seeded area. Therefore land by itself contributed about 4 to 5 million tonnes of the 17 million tonnes of additional grain produced in the last 25 years.

B. Fertility Related Increases in Production

Fertilizer use has registered a six fold increase in use between 1961 and 1986. An additional 10 million tonnes of nitrogen, phosphorous and potassium were applied by Prairie farmers. The separate contribution of each plant nutrient to total cereal grain and oilseed production is difficult to isolate. Flaten and Hedlin (1988) reviewed a number of studies on soil fertility and crop yields. They however, were unable to reach a conclusion on the combined effects of increased nutrients, pesticides and varietal improvements when all inputs were changing together. Traditional agronomic research normally does not design experiments to analyse the interactive relationships when a number of inputs are combined in different proportions.

Arthur and Kraft (1988), Arthur, Fields and Kraft (1986) and Kraft (1982) estimated the influence of varieties and fertiliser from farm level data collected between 1968 and 1980. The genetic yield potential of the crops depended upon the varieties seeded and the yield characteristics of the variety. An estimate of these yield attributes were taken from Cooperative Tests of Varieties sponsored by Agriculture Canada. Annual surveys undertaken by the Pool Elevator Companies identified the varieties seeded by farmers. Fertiliser applied and crop yields were obtained from surveys of farmers conducted by the provincial crop insurance corporations. Throughout the period, fertiliser use was correlated with increased application of herbicides. Therefore the relationships estimated between fertility and crop yields probably also jointly reflect the use of pesticides. The output elasticities estimated for wheat, barley, oats and flax with respect to fertiliser ranged between 0.1 and 0.15. In other words a 10 per cent increase in fertiliser would increase crop yields between 1 per cent and 1.5 per cent. Since fertiliser use increased 600 per cent over the period 1961 to 1986 the crop production increase attributed to fertiliser would vary from 7.7 million tonnes to 11.5 million tonnes.

The analysis of Arthur, Fields and Kraft (1986) and Kraft and (1982) estimated the elasticity for spring wheat yields with respect to the weighted yield index of the varieties seeded to be unitary. In other words a one per cent increase in the yield index of varieties grown by farmers resulted in a one per cent increase in farm spring wheat yields. Whereas the absolute yield improvement cited in the Cooperative Tests did not occur on farm, the relative change did occur. In the case of barley the variety elasticity was greater than one but not statistically different than one. The yield relationship between varieties and farm yields for oats and flax were not statistically significant. This lack of significance can probably be attributed to the paucity of new oat and flax varieties grown by farmers between 1968 and 1980. Canola (rapeseed) displayed the largest number of new varieties with an improvement but the statistical measurements of the genetic contributions to farm production were indistinguishable from the trends in fertilisers/pesticides. For wheat and barley a range of fertiliser application rates occurred with a different combination of varieties. This did not occur for canola (rapeseed) as the varietal changes were concurrent with using more fertiliser. The relationship that farm yields increased at the same rate as the genetic potential of the varieties seeded was confirmed for wheat and barley, and could not be rejected for the other crops.

Given the change of varieties seeded, and the potential yield improvement, the ultimate effect on crop production and value should be a straight forward arithmetic exercise. Equation 1 determines the annual production improvement index;

$$I_{jt} = \frac{\sum_{i=1}^{n} (Yij.Pijt)}{(Y_{ij}.P_{ij,1961})} \qquad (1)$$

where: I_{jt} - production improvement index for the j^{th} crop in the t^{th} year (t = 1962, 1963 .... 1986).

Y_{ij} - yield index for the i^{th} variety of the j^{th} crop.

$P_{i,j,t}$ - the proportion of the i^{th} variety of the j^{th} crop seeded in year t.

n - the number of varieties available in year t.

The proportion of a variety seeded in a year will depend upon its availability and productivity relative to other varieties. Figure 2 illustrates the relationship of two hard spring wheat varieties in terms of their relative share of the area seeded. Manitou was released in 1964 and by 1968 exceeded 70 per cent of the area seeded. However, the area in Manitou declined steadily after 1970 as a new variety Neepawa appeared on the scene. The share of Neepawa seeded peaked at 62 per cent in 1973 and has declined ever since. In 1973 the production index for hard spring wheat was comprised almost entirely of Neepawa (62 per cent) and Manitou (22 per cent).

Yield indices for the crops grown in Manitoba appear in Table 1. The crop indices determined from Equation 1 were each set equal 100 in 1961. Between 1961 and 1986 Canola production increased 15 per cent while barley ranked second at a 10 per cent increase. Spring wheat oats and flax only registered marginal productivity related improvements of between 2 per cent and 4 per cent during the 25 years. Spring wheat only registered a weighted average increase of 2 per cent however some areas in the Provinces grew varieties which caused the productivity to increase more.

Table 1
Production Indices for Crops Seeded in Manitoba

Year	Spring Wheat	Barley	Oats	Canola1-(Rapeseed)[1]	Flax
1961	100	100	100	100	100
1971	100	105	100	105	100
1981	101	107	101	107	102
1986	102	110	102	115	104

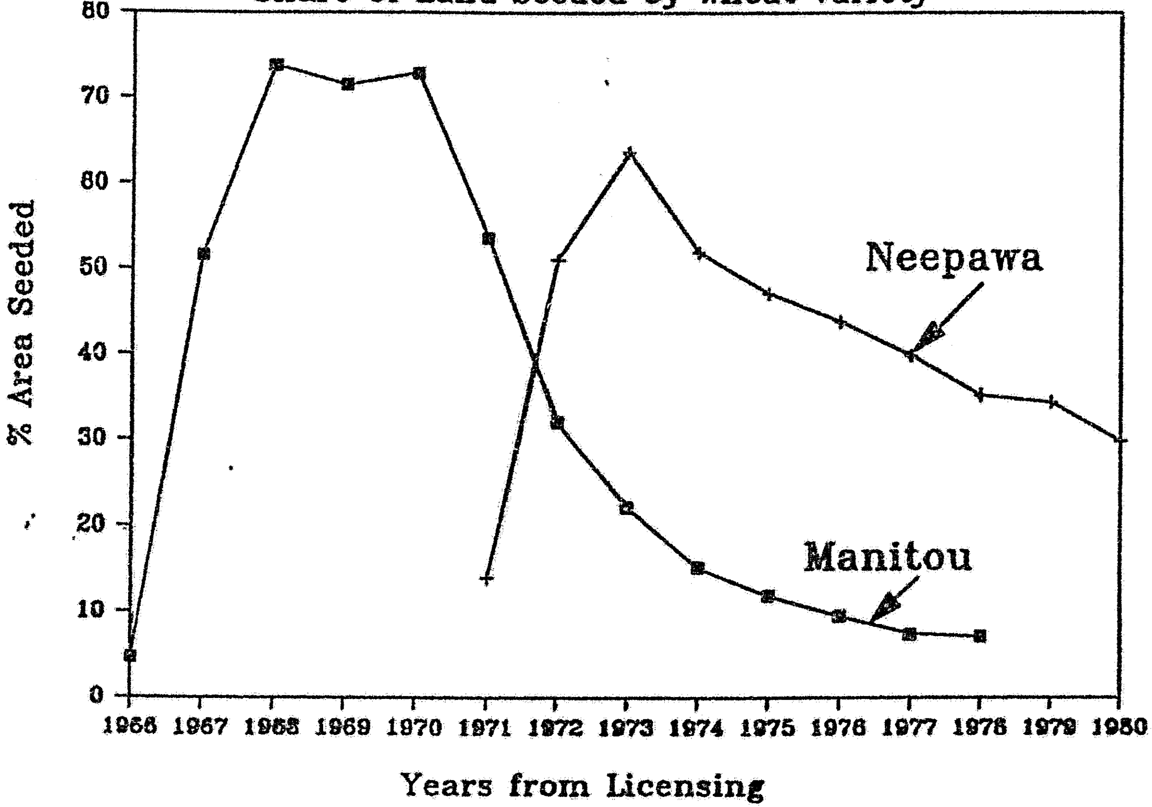
1 Index change reflects new varieties and switch from Polish (B. compestris) to Argentine (B. napus) varieties.

Previous studies by Nagy and Furtan (1978) and Akino and Hayami (1979), analysed the effects of genetic developments upon crop output by shifting or pivoting the supply function for the crop by the reciprocal of the productivity index. For example, given the 1986 Manitoba production index to Canola (rapeseed) was 1.15 (see Table 1) the procedure was to shift the supply function back to the preinnovation equilibrium by 0.87 (1/1.15).

Previous studies cited, either assume the change in the value of production is a fixed percentage cost reduction or a fixed yield increase in the form of a percentage increase in output. However, the supply function shifts by more than the yield increase because more land is allocated to the crop with the higher yielding variety. The difference in the total crop receipts between the new variety and the total revenue from the displaced crops must be determined in addition to the added revenue from producing more of the crop for the same land base.

Figure 2

Share of Land Seeded by Wheat Variety



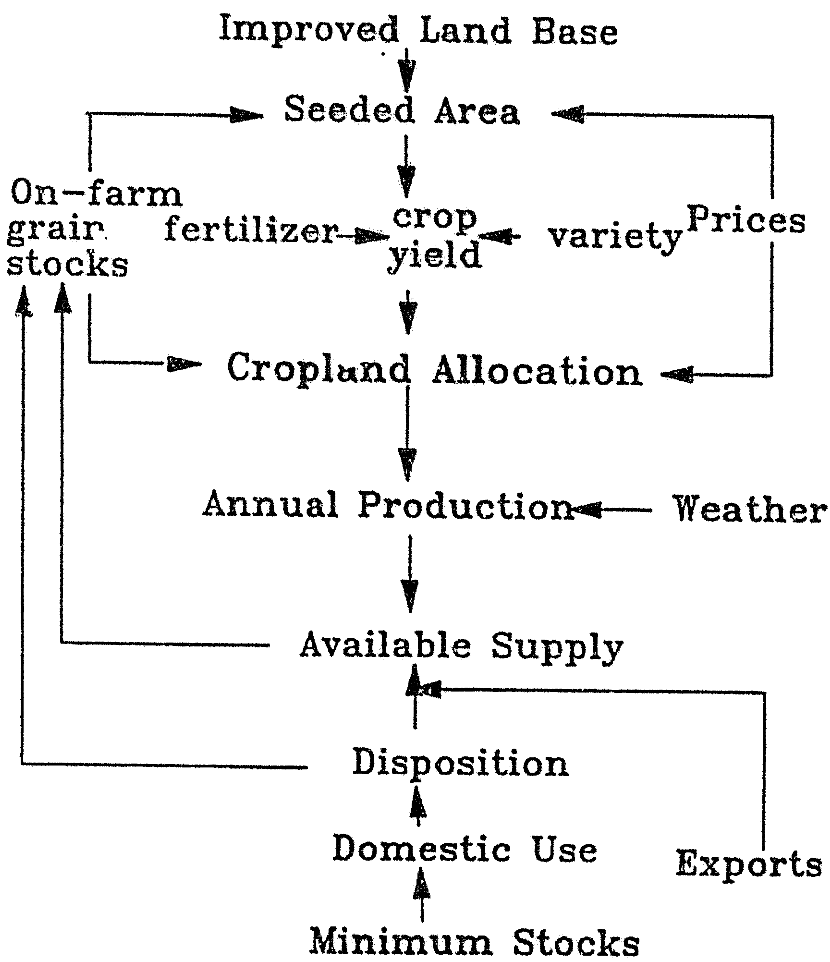
C. Economic Methodology

The approach followed in this paper is to estimate the change in the value in crop production from plant breeding for all the major crops produced in the Canadian prairie provinces. Rather than analyse just one crop, all the major cereals and oilseeds are included because each one represents an alternative to the other. Given the variable costs are similar for each crop, a yield improvement in one crop, represents higher gross margin and will likely result in a decrease in the area seeded to the others. Therefore given that prices, as well as crop yields, are changing at different rates from year to year, it was necessary to analyse all crops together in terms of their relative profitability.

Every spring, prior to planting, prairie farmers evaluate their cropping alternatives. Many factors influence their selection of which crop to grow and how much land should be seeded. Past experience in terms of the success in growing and selling the crop, along with the perception of up coming conditions all have a bearing on the seeding decision. In western Canada the five major crops are hard spring wheat, oats, barley, canola and flaxseed. The operating costs involved with seeding, tillage, fertiliser, pesticides use and harvesting are similar for each crop and therefore the relative differences in gross margin depends primarily upon crop yields and prices. A decision to plant canola means not planting wheat, barley, oats or flax. Therefore opportunity costs in terms of the margin associated with producing another crop is an important consideration in selecting the mix of crops to grow.

An econometric model was specified to account for the primary factors influencing the planting decision and they are illustrated in Figure 3. Beginning with the improved crop land base at the top of Figure 3 places limits upon how much land can be seeded to crops or summerfallowed. The total area available for crop production changes slowly overtime and has not been directly linked to genetic improvements in crop yields. The area planted every spring however, is affected by economic events such as grain prices and stocks. They influence the decision to summerfallow or reseed the land cropped the previous year. The decision with respect to the mix of crops to seed is influenced by three primary factors, namely crop prices, the grain currently in storage on the farm and crop yields. As the relative expected total value of a crop rises the tendency will be to seed more of that particular crop. For the individual farmer rotational consideration and past experience influence specialising in a particular crop and therefore modelling the economic and agronomic setting must account for the changing conditions and how farmers have responded to these events in the past.

Figure 3
Schematic of Economic Model



Varieties of each crop have a bearing upon how much crop will be seeded in terms of the expected yields, harvestability and disease resistance. As varieties are released they expand the options available to farmers and have a direct bearing upon which crop is seeded.

1. Economic Model for the Determination of Seeded Area

The total cropland base is defined as the area seeded to cereal grains and oilseeds plus the area summerfallowed. The share of the area seeded each year is estimated by equation (2).

$$Y_t = f(Y_{t-1}, T, S, P_w \text{ and } L_{1970}) \qquad (2)$$

where

Y_t = share of the cropland area seeded to cereal grains and oilseeds (%)
T = trend where t_1 is 1961 and t_{25} - 1986.
S = stocks of grain in storage on farm (tonnes)
P_w = real price of wheat when the nominal price is deflated by the farm input price index
L_{70} = a dummy variable to account for the Lower Inventory for Tomorrow program in 1970.

Last years share (Y_{t-1}) of the area seeded accounts for the rigidity of cropping decisions because of rotations, weed control and soil moisture limitations. The trend reflects the technological advancement in weed control and soil moisture conservation machinery which result in less reliance upon summerfallow being part of the rotation. As the stocks of grain accumulate the tendency is for farmers to reduce the area seeded because of limited storage capacity, and pessimistic expectations with respect to the volume of crop which maybe sold. Since wheat represents 60 per cent of the area seeded its the real price is a good indicator of the expected profitability of seeding more land. Equation 2 forecasts the area seeded between 1961 and 1986 and the only difference between the simulation with and without new varieties was the grain stocks. Surprisingly without new varieties the amount of grain in terms of total tonnes stored on farms was, on occasion, greater than with newer varieties because more wheat and less canola was produced. However over the course of the 25 years, the difference between the simulated and actual area seeded was negligible.

2. Economic Model for the Determination of Area Seeded to each Crop [see Lam (1984), Reynolds (1986) Warkentine (1989)]

The areas seeded to wheat, barley, oats, canola (rapeseed) and sunflower were estimated by a system of simultaneous equations. The estimated equations are listed below:

$$\frac{A_W}{A_F} = B_w^o \left(\frac{A_W}{A_F}\right)_{-1}^{\left(B_w^1 + B_w^2 \frac{RW}{RF} + B_w^3 \frac{RW}{RB} + B_w^4 \frac{RW}{RO} + B_w^5 \frac{RW}{RC} + B_w^6 \frac{RW}{RS} + B_w^7 IW + B_w^8 IF\right)} e \qquad (3)$$

$$\frac{A_B}{A_F} = B_B^o \left(\frac{A_B}{A_F}\right)_{-1}^{\left(B_B^1 + B_B^2 \frac{RB}{RF} + B_B^3 \frac{RB}{RW} + B_B^4 \frac{RB}{RO} + B_B^5 \frac{RB}{RC} + B_B^6 \frac{RB}{RS} + B_B^7 IB + B_B^8 IF\right)} e \qquad (4)$$

$$\frac{A_O}{A_F} = B_o^o \left(\frac{A_O}{A_F}\right)_{-1}^{\left(B_o^1 + B_o^2 \frac{RO}{RF} + B_o^3 \frac{RO}{RW} + B_o^4 \frac{RO}{RB} + B_o^4 \frac{RO}{RC} + B_o^5 \frac{RO}{RS} + B_o^7 IO + B_o^8 IF\right)} e \qquad (5)$$

$$\frac{A_C}{A_F} = B_c^o \left(\frac{A_C}{A_F}\right)_{-1}^{\left(B_c^1 + B_c^2 \frac{RC}{RF} + B_c^3 \frac{RC}{RW} + B_c^4 \frac{RC}{RB} + B_c^5 \frac{RC}{RO} + B_c^6 \frac{RC}{RS} + B_c^7 IC + B_c^8 IF\right)} e \qquad (6)$$

$$\frac{A_S}{A_F} = B_s^o \left(\frac{A_S}{A_F}\right)_{-1}^{\left(B_s^1 + B_s^2 \frac{RS}{RF} + B_s^3 \frac{RS}{RW} + B_s^4 \frac{RS}{RB} + B_s^5 \frac{RS}{RO} + B_s^6 \frac{RS}{RC} + B_s^7 IS + B_s^8 IF\right)} e \qquad (7)$$

where:

A_W - area of wheat seeded
A_F - area of flax seeded
A_B - area of barley seeded
A_C - area of canola seeded
A_O - area of oats seeded
A_S - area of sunflowers seeded

RW - expected gross margin per hectare for wheat
RF - expected gross margin per hectare for flax
RB - expected gross margin per hectare for barley
RC - expected gross margin per hectare for canola (rapeseed)
RO - expected gross margin per hectare for oats
RS - expected gross margin per hectare for sunflowers

IW - inventory of wheat stored in farms
IF - inventory of flax stored in farms
IB - inventory of barley stored in farms
IO - inventory of oats stored in farms
IC - inventory of canola (rapeseed) stored in farms
IS - inventory of sunflowers stored in farms

The lagged endogenous variable represents the tendency of farmers to continue with the previous years combination of crops. Besides the relative profitability of crops, cropping rotations and confidence to realise the expected returns will dampen the year to year switching from one crop to another. The availability of a new variety will see it replacing older varieties of the same crop first and once the revenue potential becomes more widely known it will replace other crops. Therefore it may take up to five or six years after a variety is released before the potential area seeded is attained.

The expected gross margin per acre rather than simply crop prices or yields are the most relevant indicators in terms of the profit a farmer will anticipate when growing the crop. When expected returns from one crop are divided by the expected returns for each of the other cropping options their relative profitabilities have a direct bearing on the share of the land seeded to each crop. Therefore each equation includes a set of variables to reflect the relative profitability. The expected crop prices for barley, oats, flax and canola (rapeseed) were the average cash prices in the months of January, February and March. The current Canadian Wheat Board initial prices and the most recent final price became the expected price for wheat. Expected crop yields were estimated from production functions for each crop and province [Arthur and Kraft (1988)]. The annual yield indicies for each crop represented the genetic influence in terms of the variety of crop seeded and its yield relative to a benchmark variety.

In addition to prices and yields the grain stored on farms prior to seeding was important in forecasting the area planted to each crop. Higher crop inventory prior to seeding would tend to reduce the area planted to a specific crop. Approximately 75 per cent of the cereal grain and oilseed crop production is exported from the prairie region and the limited grain handling capacity often results in lower shipments relative to the available supplies. Therefore relatively high inventories for some crops increases the probability that not all the grain will be sold during the year following harvest.

3. Elasticities Estimated from the Economic Model

Wheat has ranged between 55 per cent and 65 per cent of the seeded area and the relatively low price elasticities [0.14 to 0.15] reflect the larger area producing wheat. The relative responsiveness of the area sewed to wheat due to higher yields, prices or lower costs is associated with relatively higher reductions in the other crops. The crops with the relatively smaller seeded areas such as flax and oats have the larger cross elasticities with respect to a higher gross margin of from wheat. For example, a 1% increase in the gross margin of wheat is expected to reduce the Manitoba area seeded to oats by 0.69 per cent and flax by 0.34 per cent. Assuming operating costs are 50 per cent of total revenue then an increase in total revenue from a crop yielding 1 per cent more seed will increase gross margin by 2 per cent. Therefore in the case of Manitoba wheat, the output would increase 1 per cent from the higher yielding cultivars and 0.3 per cent due to the larger area seeded. Barley, oats, canola (rapeseed) and flax production would drop by 0.32 per cent, 1.38 per cent, 0.82 per cent and 0.68 per cent respectively as less land is seeded to these crops.

Canola (rapeseed) has the largest elasticity of all crops with respect to seeding more land when gross margins increase. The estimates range from 0.95 per cent in Saskatchewan to 1.51 per cent in Alberta. All the cross elasticities of the remaining crops are negative relative to increased earnings in canola (rapeseed). The largest relative reduction is oats in every province with respect to highest canola revenues. The increased level of output from canola (rapeseed) cultivars which yield 1 % more will likely be between 3 per cent and 4 per cent given the responsiveness of farmers to seed more land to canola. Given that equations (3) to (7) all contain lagged endogenous variables and higher crops yields have a more permanent affect upon expected revenues then price and cost changes the long run elasticity would be even higher as more land is allocated to canola.

4. Validation of the Economic Model

Prior to recreating history the validity of the model should be established. The capability of the model to track the events between 1961 and 1986 in terms of the total revenue from crop production and the areas seeded to each crop is important because the simulated history becomes the bench mark for comparing different crop variety scenarios. Validation is evaluated in terms of three measurements, namely root mean percentage error (RMS% error), mean per cent error and R^2. The RMS % error is determined by equation 8.

$$\text{RMS\% error} = \frac{(A_t - P_t)^2}{A_t^2} \quad (8)$$

where: A_t - the actual value of a variable in period t
P_t - the predicted value of a variable in period t

A perfect forecast would result in a RMS% Error of 0

Table 4

Forecasting Performance of the Model

	Performance Statistic		
Variable	R^2	RMS% Error	Mean % Error
Wheat Revenue	.99	3.6	.55
Barley Revenue	.98	7.4	.05
Oats Revenue	.96	6.5	1.50
Flax Revenue	.90	17.1	-5.11
Canola Revenue	.97	17.3	2.84

The overall forecasting performance of the model was judged to be acceptable with the lowest error being recorded for wheat. The model tended to overestimate the total area in crop production. All forecasted revenues except flax tended to exceed the historical revenue. Given that prices were assumed not to be influenced by the level of crop production the only variable which caused the forecasted revenue to exceed the actual was the quantity of production. The mean per cent error for barley was the lowest, however, the forecast errors about the mean were larger than wheat and oats. The oilseed crops appeared to be the most difficult to forecast. The largest mean per cent error was -5.1 per cent for flax. The model simulation appeared to be sufficiently sound to represent and compare two different historical scenarios.

5. Scenarios Analysed by the Economic Model

The benchmark scenario became the simulated history with farmers adopting the new varieties as they had in the past. One of the alternate scenarios assumed the plant breeding programs released no new varieties after 1961. The other scenario assumed the canola (rapeseed) breeding programs were never sta: ;ed out the varieties of wheat, oats and barley and flax were released and adopted at the same rate as they were historically.

C. Results

(1) Value of Production

During a twenty-five year time interval (1961-86) prairie farmers were simulated to produce $c101.5 billion of cereal grains and oilseeds. The actual value was $c101.9 billion. If no new plant varieties were released after 1961 then the value of twenty five year accumulated cereal grain and oilseed production was simulated to be $c95.2 billion. Over the period of 25 years the value of cereal grains and oilseeds produced was simulated to be $c5.6 billion lower without new varieties on 5.3 per cent of the total value of production. The income contributed by the new varieties is nearly equal to the added value of production since the differential cost of seeding newer varieties diminishes as their availability expands over time. The aggregate net farm income contributed by new varieties between 1961 and 1986 was estimated to be $c5.0 billion dollars or $c200.0 million annually.

Table 4 shows the annual revenue from all crops for each of the three scenarios. The difference between the revenue produced from all crops and either of the scenarios with fewer crop varieties is an estimate of the income the new varieties contributed. During the 1960's the newer varieties contributed $c0.2 billion.

Canola varieties added very little additional income during the 1960's. By the 1970's all new varieties were simulated to add $c1.7 billion. Canola varieties alone were determined to contribute $c0.4 billion to farm income during the 1970's.

During the 1980's $c1.2 billion of $c3.7 billion crop variety related income was associated with the canola varieties released since 1961. By 1986 10.5 per cent of the total value of all crops produced was linked to varieties released in the past 25 years. Canola accounted for over half of the added value from varieties in 1986.

The relative importance of canola's (rapeseed) contribution through new varieties is measured in terms of the total added income between 1961 and 1986. New canola varieties contributed $c1.6 billion of the $c5.6 billion from all varieties. The importance of canola (rapeseed) developments will be examined in more detail later.

2. Crop Rotations

The significance of variety developments is registered through the diversification of the crops produced. Table 5 shows that if no new varieties were released after 1961 the relative importance of wheat, the most dominant crop in the Prairies, would have been even greater. Wheat production was simulated to contribute $c59.7 billion between 1961 and 1986 with historical variety developments but would have equaled $62.4 billion with no new varieties. In other words low yielding wheat varieties would have produced more wheat because more land would have been seeded to wheat. During the 1960's there was little difference between the historical simulations and the no new variety simulations with respect to the area producing wheat, however simulations of the 1970's resulted in at least 5 per cent more land growing wheat and up to 15% more in 1978. The 1980's averaged 10 per cent more land in wheat if 1961 varieties were the only choices available to farmers.

If canola (rapeseed) variety developments had not occurred but the historical varieties of wheat, barley and oats and flax were available wheat production over the 25 years was simulated to be 5 per cent higher than it was historically. During the 1960's the influence of canola varieties was negligible in terms of wheat production. By the 1970's the value of wheat production was lowered by $c1.2 billion or 6.1 per cent because land was seeded to canola (rapeseed) instead of wheat. Between 1980 and 1986 wheat production was estimated to be $c1.7 billion lower (5.4 per cent) then it would have been without the option of seeding the varieties of canola released in the past 25 years.

The growth of canola production attributed to the variety development after 1961 was simulated to occur predominantly in the 1970's and 1980's. The first new varieties (Tahka, B. napus) and Echo (B. campestris) were released in 1964. By 1969 they were grown upon 46 per cent of the land. (Nagy and Furtan, 1978.) By 1970 only 5 per cent of the area was seeded to varieties available prior to 1962 and in two years (1972) the older varieties were no longer seeded. The simulated ten year canola revenue without the varieties was $c1.7 billion but with the varieties the revenue was estimated to be $c4.2 billion or a 247 per cent increase. In the

1970's, the newer varieties yielded 7 per cent more each year or 70 per cent of the added output relative to growing the older varieties. The remaining 177 per cent was attributed to additional land seeded to canola. The land seeded to canola was two times higher with variety development but since some of the additional area seeded was on less productive land (stubble). Therefore the increase in production was less than the increase in area. For the seven years simulated in the 1980's the canola varieties averaged 10 per cent per year or a 50 per cent cumulative increase in production due to the varieties grown relative to no genetic improvement. The area seeded to canola was simulated to be 2.3 times greater than with no variety improvements. In the absence of the yield improving varieties of canola the area seeded in 1986 was predicted to be no higher than it was prior to the introduction of new varieties in the later 1960's.

Limiting the value of plant breeding too just higher yields ignores the contribution of quality changes. This is particularly true for canola (rapeseed) with the improvements in the erucic acid, glucosinolates and fiber content of the newer varieties. The economic model, however, provides some insight with respect to the magnitude of the benefits. Qualitative changes could be reflected in terms of the price of the crop. Varieties of canola with higher concentrations of erucic acid or glucosinolates would be discounted in terms of lower prices. This in turn represents a lower expected gross margins from growing these varieties. Lower revenues can be incorporated into the economic model in the same manner as lower yielding varieties. Assuming that lower quality canola (rapeseed) would sell for 10 per cent less, then the model indicates that the 25 year (1961-86) canola (rapeseed) production with the older varieties would be approximately $c1.8 billion. This represents a further reduction of canola (rapeseed) output from the 25 year cumulative level of $c10.7 (Table 6). Canola (rapeseed) production was simulated to be only $c4.2 billion when just yield was influenced by the newer varieties. Adding the loss of quality to yield suggests the value of canola (rapeseed) would have declined further to $c1.8 billion. The estimate of $c1.8 billion may in fact be too high because if the quality improvements prevented only a 10% price discount then without the yield and quality improvements canola (rapeseed) would have returned an income comparable to the other crops. Without the yield and quality occurring together canola would likely only be a minor specialty crop in the prairie provinces. Assuming this to be the case then the income attributed to genetics would be the difference between canola (rapeseed) receipts and the mix of crops it replaced. In Table 5 the income attributed to canola (rapeseed) variety development was $c1.7 billion between 1962 and 1986. If canola remained at a level of production it had in 1961 because the varietal yield and quality changes were nonexistent then the loss in farm income would be $c2.2 billion or nearly a hundred million per year.

Table 4
Simulated Value of Prairie Cereal Grain and Oilseed Production and Revenue Attributed to Yield Related Varietal Development

	Total Crop Revenue			Income Lost	
Years	Past Variety Development All Crops	No Variety Development All Crops	No Variety Development Canola	No variety Development All Crops	No Canola Variety Development
	$c - Billion				
1962-69	14.6	14.4	14.6	.2	0
1970-79	37.7	36.0	37.3	1.5	.4
1980-86	49.2	45.5	48.0	3.3	1.1
1962-86	101.5	95.9	99.9	5.0	1.4

Table 5
Simulated Value of Wheat Production in the Canadian Prairies

Time	Historical Variety Development all Crops	No Variety Development All Crops	No Variety Development Canola
	$c Billion		
1962-1969	9.4	9.4	9.4
1970-1979	20.8	22.0	22.0
1980-1986	29.5	31.1	31.2
1962-1986	59.7	62.4	62.7

Table 6
Simulated Value of Canola (rapeseed) Production in the Canadian Prairies.

Time	Historical Variety Development all Crops	No Variety Development All Crops	No Variety Development Canola
		$c Million	
1962-1969	.4	.3	.3
1970-1979	4.2	1.8	1.7
1980-1986	6.0	2.4	2.2
1962-1986	10.7	4.6	4.2

IV Conclusions

A. The Canadian Case Study

Plant breeding through increasing the yields of cereal grains and oilseeds was simulated to have contributed $c5.0 billion to farm income between 1962 and 1986. The $c220 million average annual increase in income should be compared to the annual expenditures on research and development for cereal grains and oilseeds.

Assuming perfect elastic demand, the supply elasticities estimated for crops with relatively smaller shares of Canadian production (barley, oats, canola (rapeseed) and flax) indicate the increase in income from the added area producing a crop exceed the increase due to the higher yields. In the case of the Canadian prairie provinces the major genetic improvements have been in barley and canola (rapeseed). The effect of these developments has been to diversify the mix of crops grown by farmers as without the higher yields fewer hectares would be seeded to barley and canola (rapeseed) and more to wheat. In fact the simulations suggested that more wheat would be produced in western Canada if farmers only had the 1961 varieties available to them during the following twenty-five years.

B. Biotechnology and economic evaluation

1. Research funding

The economic surplus approach used to evaluate returns to agricultural innovations is conceptually sound but partial in nature. Evaluation of commodity specific innovation will likely represent a smaller set of future technological changes. Therefore methodologicial work is required to expand the partial comparative statics framework to include more markets (commodities, product quality dimensions, and other natures) and the underlying market structure resources. If our discipline doesn't build onto the partial framework it will be able to make limited comments on income distribution and the magnitude of the gains from innovations.

The trend toward funding agricultural research from revenues raised by taxing a commodity or a factor of production may exclude selecting the most promising projects. Commodity specific research committees tend to fund only those inquires with a direct bearing on the industry in question. Commodities with the greatest total revenue will dominate the research progress and commodities with low or non existent research funds will have minimal influence in directing the scientific work. The possibility that the net economic gain to society or even producers controlling resources capable of producing competitive commodities would be larger if the commodity generating lower research funds received more support. I suggest that if research funds were industry driven in the 1960's the Canadian and world rapeseed industry would have a much lower share of the vegetable oil market and may be non existent. Without the contribution of barley and (rapeseed) related income, plant breeding in western Canada would have contributed less income then the costs of operating the programs. Public support or a portion of the commodity specific research funds is required for the infant industries. The duration of the support would have to be analysed on a case by case basis.

Similarly, basic research does not have an industry specific sugar daddy but underpins the technological innovations. Likewise a portion of the industry specific research budget along with public revenue is required to finance the basic scientific community. The amount of support an individual nation chooses to allocate to the expanding the frontiers of knowledge depends upon wealth and the willingness of other nations to finance these endeavours.

Table 2: Estimated Own Cross-price Elasticities of Supply for Grains and Oilseeds for increases in prices or reduction of costs[1,2]

Crop w.r.t. the gross margin of	Manitoban Crop				
	Wheat	Barley	Oats	Canola	Flax
Wheat	.15	-.16	-.69	-.41	-.34
Barley	-.04	.50	-.18	-.93	-.11
Oats	-.01	.03	.19	-.72	-.04
Canola	-.05	-.13	-.28	1.39	-.03
Flax	-.11	-.19	-.27	-.04	.51

Crop w.r.t. the gross margin of	Saskatchewan Crop				
	Wheat	Barley	Oats	Canola	Flax
Wheat	.15	-.22	-.38	-.23	-.79
Barley	-.05	.67	-.04	.08	-.06
Oats	-.01	-.44	.61	-.15	-.02
Canola	-.05	-.04	-.41	.95	-.07
Flax	-.03	-.05	-.11	.15	.94

Crop w.r.t. the gross margin of	Alberta Crops				
	Wheat	Barley	Oats	Canola	Flax
Wheat	.14	-.06	-.53	-.03	-.75
Barley	-.01	.20	.04	.18	-.34
Oats	.10	-.03	.73	-.71	-.10
Canola	-.20	-.01	-.39	1.51	-.30
Flax	-.02	.04	.14	-.35	1.50

1 Point elasticities reflect prices, yields, areas seeded and costs in 1986.

2 A one per cent increase in yield will increase the elasticity of the crop affect by one per cent plus its own elasticity shown here.

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