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ABSTRACT

The level and distribution of the social benefits from public investment in Canadian wheat breeding research and extension activities are examined for the period 1946 to 1979. In addition, average and marginal rates of return are calculated. The results reveal that society has benefited substantially from such public investments, with producers receiving the greatest share of the benefits.

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1. Introduction

In Canada, over 95 percent of the agricultural research activities are supported by public funds (McGlaughlin 1977). The principal rationalization or justification for these expenditures is the expectation that the resulting knowledge (from the research discovery process) will produce a sustained stream of increments to the goal levels of society greater than the opportunities foregone.

Over the past several decades, doubts have risen regarding the social value of these public investments and the efficiency with which the scarce resources are being allocated among the full array of public investment opportunities. These concerns have been expressed through a strengthening of the requirements going into the conduct of agricultural research. Public research scientists and resource administrators are being held more accountable for the resources being utilized, and for the impacts on members of society from the technologies and information that are generated. This, in turn, has created the need for more and better information on the nature, extent, and distribution of the social benefits and costs from such investments. As of to date, there has been little effort undertaken in Canada to examine and quantify these aspects.

The purpose of this study was to begin to fill this void. The study focuses on public wheat breeding research activities conducted over the period 1946 to 1979.[1/] Wheat was defined to include spring wheat, durum, and winter wheat. The specific objectives of the study were:

1) to measure the social costs and benefits, and the social rates of return (both average and marginal) from public investment in the development of genetically superior wheat varieties, and
2) to assess the extent to which the benefits from the public wheat breeding research activities accrue to producers and non-producers (i.e., consumers), respectively.

[1/] This report was written from a larger study that was undertaken as a Ph.D. thesis project at the University of Minnesota (Zentner 1982).

2. Theoretical and Methodological Considerations

2.1 Social Costs of Public Wheat Breeding Research

Estimates of public expenditures on wheat breeding research were made from information on person-years obtained from annual listings of professional personnel at the various research institutions (e.g., federal research stations and agencies, faculties of agriculture, and provincial governments). Wheat breeding research was defined to include only those activities related to the development of new wheat varieties, wheat genetics, and wheat variety assessment. The person-years were converted into monetary values by an estimated annual cost to support a professional crop scientist.2/ The monetary values were deflated to 1971 dollars by an index of associate professors salaries (Table 1).3/

Annual estimates of wheat variety extension expenditures were made from the public accounts of the provincial governments and the relevant departments in the Federal government and universities (Table 1). Because of the lack of adequate categorization in the financial records, an apportioning procedure was used. It consisted of two assumptions. First, the proportion of the total agricultural extension expenditures applicable to the production of wheat was assumed to be in direct relation to the importance of the crop. A five-year moving average ratio of wheat sales to total farm income was used to estimate the "total wheat" extension expenditures. Second, the proportion of the total wheat extension expenditures applicable to the dissemination of

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2/ Annual cost estimates (both variable and overhead costs) were made because of changes in the real costs of conducting research. The techniques of experimentation and investigation have become more complex and sophisticated over the years (as have the problems themselves) and the equipment and necessary resources have become correspondingly more expensive. On the other hand, new equipment (e.g., computers) has been installed primarily to reduce the amount of time and resources utilized in collecting and processing data.

3/ An index of associate professors salaries was used to deflate the research and extension expenditures to real dollars instead of the commonly used Consumer Price Index (CPI). This was done because professional salaries, which weigh heavily in the total research and extension expenditures, have risen substantially faster than the CPI over the past 30 years. Consequently, using the CPI would grossly underestimate past research and extension expenditures relative to those in current time periods.

information and knowledge (to producers) about new wheat varieties was assumed to be in direct relation to the ratio of expenditures on wheat breeding research relative to the total wheat research activities. A five-year moving average ratio was used. The wheat variety extension expenditures were deflated to 1971 dollars by an index of associate professors salaries.

2.2 Social Benefits from Public Wheat Breeding Research

The concept of economic surplus (and its components - consumers' surplus and producers' surplus) formed the basic theoretical framework for measuring the level and distribution of the social benefits from public wheat breeding research.4/ The constant price elasticity model developed by Hayami and Akino (1977) was used in the analyses.5/ Implementation of the methodology requires annual information on several aspects. These include price elasticities of supply and demand for wheat, equilibrium price and quantity, and magnitude of the production function shift attributable to the new wheat varieties.6/ The price elasticity of supply (i.e., 1.2364) was taken from an empirically estimated equation and was assumed to be constant throughout the period of study (Zentner 1982). The price elasticity of total wheat demand was computed annually by weighting the elasticities of the domestic and foreign components by their relative importance (Table 1). The annual equilibrium price and quantity of wheat were taken from published records.

4/ The use of the economic surplus approach as a methodology to measure changes in economic welfare is common in the economics literature, thus it will not be discussed in this report.

5/ All empirical studies that employ the economic surplus framework utilize the properties of the ordinary Marshallian demand function (instead of the theoretically correct Hicks Compensated demand function) in calculating the change in economic surplus. Such a procedure introduces little bias into the analysis if one of the following conditions are present. One, is that the income elasticity of demand for the product is low, or two, the product represents a small share of the consumer's budget expenditures. In the case of wheat, both of these conditions apply (see for example Hussan and Johnson 1976).

6/ Because of space limitations, only the latter aspect is discussed in some detail in this report. Readers that are interested in the details of the other aspects can consult Zentner (1982).

The annual shifts in the aggregate wheat production function attributable to public wheat breeding research were obtained by calculating the weighted average yield increases of the new varieties relative to chosen base varieties for each type of wheat, assuming the same level of total inputs. The weights used were the proportions of the total wheat area actually planted to the new varieties.7/

Thatcher for hard red spring wheat, Mindum for durum, and Kharchow 22 MC for winter wheat were chosen as the base varieties. Results from the "Cooperative Wheat Variety Trials" conducted under the auspices of the Expert Committees on Grain Breeding, Grain Diseases, and Grain Quality were used in computing the varietal contributions. The weights or variety proportions were taken from the "Annual Wheat Variety Survey" conducted by the Cooperative Producers Limited, and previous to 1972 by the Searle Grain Company and Line Elevator Farm Services.

Several aspects about the estimation procedure, data sources, and assumptions deserve comment. The first aspect concerns the choice of base varieties. All of the base varieties were developed outside of Canada. They were introduced into Canada by plant breeders in the late 1920's and 1930's. Soon after their introduction, they gained wide acceptance by producers. Some of them have maintained commercial significance almost to the present day. To have selected Canadian varieties as the base (e.g., Marquis for hard red spring wheat) would have attributed the social benefits of the foreign varieties to Canadian wheat breeders. This would greatly overstate the contributions of the Canadian wheat breeding research effort. Another

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7/ The formula used for computing the annual shifts in the aggregate wheat production function (K_t) was:

$$K_t = \sum_i \sum_j \left[\frac{Y_{ijt} - Y_{bjt}}{Y_{ijt}} \right] \frac{A_{ijt}}{A_t}$$

where, i = wheat variety ($i = 1,2,\ldots,I$),
j = geographical region ($j = 1,2,\ldots,J$),
t = time period or year ($t = 1,2,\ldots,T$),
Y_{ijt} = average test site yield of variety i in region j and period t,
Y_{bjt} = average test site yield of base variety b in region j and period t,
A_{ijt} = area sown to variety i in region j and period t, and
A_t = total area of wheat sown in period t.

Table 1. Annual Estimates of Wheat Breeding Research and Wheat Variety Extension Expenditures, Elasticities of Total Wheat Demand, and Aggregate Wheat Production Function Shifts, 1946-1979

Year	Wheat Breeding Wheat Expenditures	Wheat Variety Extension Expenditures	Elasticity of Total Wheat Demand	Aggregate Wheat Production Function Shifts[1/]
	(thousands of 1971 dollars)			(percent)
1946	666.9	265.3	-2.47	-
1947	754.9	372.3	-3.78	-
1948	979.7	430.3	-3.61	-
1949	1060.0	460.9	-3.05	-
1950	1099.4	455.4	-3.10	-
1951	1107.6	460.3	-2.47	-
1952	1160.5	485.6	-2.55	-
1953	1154.2	520.0	-2.35	-
1954	1223.1	516.1	-2.93	-
1955	1211.6	506.2	-3.12	-
1956	1277.3	472.8	-3.93	2.22
1957	1215.8	473.8	-3.22	3.00
1958	1170.7	434.4	-3.64	2.86
1959	1106.1	425.6	-4.16	2.60
1960	1102.7	441.2	-4.17	0.21
1961	1120.4	452.4	-4.52	0.32
1962	1106.5	452.2	-4.48	0.84
1963	1123.7	504.9	-3.66	0.93
1964	1175.8	520.5	-4.00	0.92
1965	1220.6	503.7	-4.23	0.82
1966	1240.1	515.9	-3.62	1.08
1967	1187.8	532.3	-5.31	2.31
1968	1235.4	519.0	-4.57	3.19
1969	1325.9	520.4	-5.14	3.88
1970	1321.5	526.6	-4.41	3.32
1971	1311.0	583.3	-3.62	3.31
1972	1391.1	569.4	-4.33	4.97
1973	1360.5	632.9	-5.13	5.59
1974	1338.6	793.2	-5.36	6.40
1975	1329.0	864.3	-5.28	6.73
1976	1371.9	843.6	-4.63	6.90
1977	1363.0	837.1	-4.50	7.39
1978	1347.1	838.1	-5.66	7.79
1979	1369.6	843.5	-7.11	7.83

1/ 1956 was selected as the first year in which the production function shifts were calculated in order to facilitate research lags of up to 10 years when computing the social rates of return.

reason for the choices was the fact that the base varieties were maintained as "standards of comparison" in the Cooperative Tests throughout the period of study.

A second aspect requiring comment relates to the use of experimental data. It is well recognized that experimental yields overestimate farm level yields. In this study several factors tend to reduce the level of "experimental" bias. First, only percentage changes in yields (and not absolute yield levels or differences) were used. It may not be unreasonable to expect that the same proportional changes apply at the farm level. Second, the application of fertilizers, herbicides, and insecticides used in the Cooperative Tests were generally set at recommended levels and not output maximizing levels. Third, the Cooperative Tests were conducted over a significant number of locations within each region and the average results used in this study.

A final aspect deserving of comment relates to the consideration of only yield effects. By focusing only on yield, changes in grain quality are ignored. If the new wheat varieties have higher milling and baking quality characteristics as a result of the breeding efforts, then the social benefits being attributed to Canadian wheat breeding will be biased downward. In Canada, statutory quality standards have been established for plant breeders. These standards are considered to be exceptionally high relative to those of other countries. As stated by Walton (1968, p. 601), in Canada "The objective of all hard red spring wheat breeding programs for well over 50 years has been to produce strains equal in quality to Marquis with added factors aimed to improve yield". This notion is supported by the overall quality ratings of the major hard red spring wheat varieties in which none of the new wheat varieties were rated as superior to Marquis (Canadian International Grains Institute 1975). Consequently, quality improvement considerations can be left out of the analysis without causing significant bias.

3. Results and Discussion

3.1 The Level of Social Benefits

The level of social benefits attributable to public wheat breeding research were

calculated for the period 1956 to 1979 (Table 2).[8] The calculations were made using the formulas (for the change in consumers' and producers' surpluses) derived by Hayami and Akino (1977, p. 52-54), together with the supply elasticity assumption of 1.2364 and the production function shifts and demand elasticities given in Table 1. These parameter assumptions comprise what is referred to as the "base situation". However, since it could be argued that these parameters may be subject to error, six additional analyses were performed to evaluate the sensitivity of the social benefits (as well as for the distribution of social benefits and the social rates of return) to changes in the base assumptions. In the first instance, the annual production function shifts were varied 20 percent below (i.e., $0.80 * K_t$) and 20 percent above (i.e., $1.20 * K_t$) those reported in Table 1, certeris paribus. In the second instance, the supply elasticity was halved (i.e., $0.50 * \varepsilon_t$) and doubled (i.e., $2.0 * \varepsilon_t$) from the base value. In the third instance, the annual demand elasticities were halved (i.e., $0.50 * \eta_t$) and doubled (i.e., $2.0 * \eta_t$) from those reported in Table 1.

The results reveal that society has benefited substantially from public investment in wheat breeding research. The annual level of social benefits ranged from 2 million dollars (1971 prices) in 1960 to 141 million dollars (1971 prices) in 1979. The high annual variation in the level of social benefits is attributable to changes in weather conditions and marketing opportunities for wheat and other grains. Furthermore, during the decade beginning in 1960, the level of social benefits were relatively low compared to those in the following decade. This pattern can be attributable to at least three factors. The first is that the general climatic or environmental conditions may have changed over the period of the study, which in turn, affected the relative performance of the new varieties (e.g., more rainfall in the 1970's versus the 1960's, or more favorable growing conditions leading to reduced problems with disease and insect pests). A second explanation may be that the research discovery process applicable to

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8/ 1956 was selected as the first year in which the social benefits were calculated in order to facilitate research lags of up to 10 years when computing the social rates of return.

the 1960's did not produce much in terms of higher yielding varieties, and consequently, producers had few superior varieties to adopt. The third and most plausible explanation is that producers lacked adequate economic incentives for wheat production and the rapid adoption of new varieties developed by research. Throughout the 1960's huge stockpiles of wheat were accumulating on farms (e.g., by 1970 farm stocks were equivalent to about 2 years of production), reflecting the lack of marketing opportunities and generally depressed prices for wheat. However, in the early 1970's this trend reversed as world demand for Canadian wheat suddenly increased causing prices to rise to unprecidented levels. The high prices and good marketing opportunities, in turn, made the new wheat varieties (and complementary inputs such as fertilizers, herbicides, and insecticides) economically feasible for producers to adopt.

The level of social benefits were quite sensitive to changes in the magnitude of the production function shifts, but rather insensitive to the assumptions about the supply and demand elasticities. Finally, the level of social benefits in any one year tended to be far in excess of the social costs in that same year. However, since research is an investment activity that incurs costs and (sometimes) produces a stream of benefits over a period of time, valid comparisons of the social benefits and costs must be made by computing the social rates of return.

3.2 Average Social Rates of Return

The average internal rates of return for the various scenarios were computed using the iterative procedure outlined by Peterson (1971, p. 149). Two alternative social cost measures were examined (Table 2). The first included only the level of wheat breeding research expenditures as social costs, while the second included the combined expenditures on wheat breeding research and wheat variety extension. A research lag (i.e., time period before a research investment brings forth positive social benefits) of 10 years was assumed. All calculations were made by compounding the historical net social benefits (social benefits minus social costs) to 1979, and discounting back to

1979 all future net social benefits by the internal rate of return. The 1977-79 average net social benefit was used as an estimate of all future returns to society from the new wheat varieties.

The average internal rate of return, using the base situation assumptions and the level of wheat breeding research expenditures as the measure of social costs, was 34 percent. This implies that, on average, each dollar invested in the development of genetically superior wheat varieties has produced an annual return to society of 34 percent (or $0.34) from 1946 into perpetuity. The effect of using the combined wheat breeding and wheat variety extension expenditures as the measure of the social costs was to lower the average internal rates of return by about 5 percentage points.

The average internal rates of return were insensitive to changes in the supply and demand elasticity assumptions, and moderately sensitive to changes in the magnitude of the production function shifts. Furthermore, the average internal rates of return were moderately sensitive to the length of the research lag assumptions. Research lag assumptions of 9 and 8 years resulted in average rates of return that were about 4 and 8 percentage points higher, respectively.

3.3 Marginal Social Rates of Return

A rough or first approximation of the marginal rate of return was obtained using the procedure outlined by Peterson (1971, p. 150). A 10 year research lag was assumed. The results of this analysis show that the marginal rate of return was 44 percent. This implies that the last dollar invested in wheat breeding research produced an annual return of 44 percent (or $0.44) into perpetuity. In an *ex ante* sense, it implies that an additional dollar invested in wheat breeding research will produce an annual rate of return of about 44 percent. The marginal rates of return displayed similar sensitivities to changes in the base assumptions as for the average rates of return.

3.4 Distribution of Social Benefits

Public support for wheat breeding research is considered necessary in order to

Table 2. Estimates of Social Benefits (Million Dollars in 1971 Prices), Average Social Rates of Return (Percent), and Proportion of Social Benefits Captured by Producers (Percent) from Public Wheat Breeding Research Activities

Year	Base Situation[1]	Sensitivity of the Social Benefits to Changes in the Base Situation Assumptions					
		$0.8*K_t$[2]	$1.2*K_t$[3]	$0.5*\varepsilon_t$[4]	$2.0*\varepsilon_t$[5]	$0.5*\eta_t$[6]	$2.0*\eta_t$[7]
1956	15.99	12.77	19.23	15.93	16.16	16.10	15.92
1957	24.94	19.89	30.03	24.78	25.31	25.18	24.77
1958	22.44	17.90	27.01	22.31	22.74	22.63	22.31
1959	19.33	15.43	23.25	19.24	19.55	19.47	19.23
1960	2.15	1.72	2.58	2.15	2.15	2.15	2.15
1961	3.53	2.82	4.24	3.53	3.54	3.53	3.53
1962	8.21	6.56	9.86	8.20	8.24	8.23	8.20
1963	15.14	12.10	18.18	15.11	15.20	15.18	15.11
1964	9.86	7.88	11.85	9.85	9.90	9.89	9.84
1965	12.37	9.89	14.85	12.35	12.41	12.40	12.35
1966	15.09	12.06	18.13	15.05	15.16	15.14	15.05
1967	21.00	16.77	25.24	20.92	21.18	21.12	20.91
1968	21.95	17.52	26.42	21.83	22.25	22.15	21.82
1969	26.65	21.25	32.07	26.48	27.05	26.92	26.47
1970	29.61	23.62	35.64	29.44	30.03	29.89	29.43
1971	30.51	24.32	36.73	30.30	30.98	30.81	30.29
1972	68.46	54.53	82.52	67.85	69.92	69.42	67.81
1973	136.57	108.79	164.59	135.34	139.56	138.55	135.26
1974	124.59	99.20	150.22	123.35	127.63	126.61	123.27
1975	116.23	92.52	140.18	115.00	119.24	118.22	114.92
1976	92.33	73.45	111.43	91.24	94.95	94.05	91.17
1977	106.24	84.46	128.29	104.87	109.51	108.38	104.79
1978	117.37	93.38	141.62	116.00	120.74	119.62	115.92
1979	140.85	112.16	169.80	139.45	144.40	143.25	139.37
R.O.R.[8]	34	31	37	34	35	34	34
R.O.R[9]	29	26	32	29	30	29	29
Producers share[10]	62.2	61.8	62.5	68.8	53.0	38.3	78.7

1/ The base situation assumptions include K_t and η_t parameters given in Table 1, ε_t = 1.2364, and a research lag of 10 years

2/ Refers to 80 percent of the estimated annual aggregate production function shifts given in Table 1

3/ Refers to 120 percent of the estimated annual aggregate production function shifts given in Table 1

4/ Refers to 50 percent of the assumed supply elasticity, i.e., ε_t=0.6182

5/ Refers to 200 percent of the assumed supply elasticity, i.e., ε_t=2.4728

6/ Refers to 50 percent of the annual estimated demand elasticities given in Table 1

7/ Refers to 200 percent of the annual estimated demand elasticities given in Table 1

8/ Refers to the average rate of return (1946-79) when using the level of wheat breeding research expenditures as the measure of social costs

9/ Refers to the average rate of return (1946-79) when using the combined expenditures on wheat breeding research and wheat variety extension as the measure of social costs

10/ Refers to the average (1956-79) proportion of the social benefits captured by producers. The proportion captured by consumers is one minus these figures.

attain a socially optimum level of investment. However, if the major share of the social benefits from the research are captured by one group or another, then it might be more appropriate, in terms of equity criteria, to let the groups share in the investment costs in proportion to the benefits received.

The theoretical framework used in this study provides a means for estimating the proportion of the total social benefits going to producers and non-producers (i.e., consumers), respectively.9/ The results are shown in Table 2. They reveal that both producers and consumers share in the social benefits from public wheat breeding research. Producers received an average of 62.2 percent of the total social benefits, while consumers received the remaining 37.8 percent (using the base situation assumptions).

The social benefits received by producers will be divided among the factors of production in inverse proportion to their elasticity of supply. Since the supply of land is highly inelastic in nature, land owners receive a proportionally large share of the benefits going to producers in the form of an increased rent to land. The increased economic rent, in turn, becomes capitalized into the price of farm land.

Similarly, since nearly 75 percent of the annual Canadian wheat production is exported, a sizeable share of the social benefits going to consumers is actually passed along to foreign countries. This transfer takes the form of larger quantities of wheat and wheat products being made available at lower prices. However, Canadian consumers (and producers) benefit indirectly, at least to the same extent. The increased foreign exchange earnings from the additional wheat exports enable Canadians to purchase foreign goods and services at lower prices.

The distribution of social benefits between producers and consumers were extremely sensitive to changes in the demand elasticity assumptions. Reducing the demand

9/ Unfortunately, the theoretical framework has several limitations for this type of analysis. For example, it is only a partial equilibrium approach and, consequently, ignores all second-order effects. Furthermore, it ignores many of the equity and interpersonal utility comparison issues for members within and between groups (e.g., do large producers benefit relatively more or less than small producers; how are the social benefits distributed between low and high income consumers).

elasticities by one-half resulted in producers capturing only about 38 percent of the total social benefits, while doubling the demand elasticity raised the proportion of the social benefits going to producers to about 79 percent. The distribution of the social benefits were insensitive to changes in the aggregate production function shifts, and moderately sensitive to changes in the supply elasticity assumptions.

Summary and Conclusions

In view of the 10 to 20 percent average rate of return that would be considered acceptable for most ordinary investments, one is justified in concluding that past investment in public wheat breeding research has produced a high return for society. At the same time, however, it must be remembered that these are returns to past research investment and do not necessarily guarantee that similar levels of social benefits will come forth from future investment in public wheat breeding research.

In terms of providing allocative guidance for future investment decisions, the high marginal rates of return imply that society has likely not over-invested in wheat breeding research (i.e., driven the marginal rate of return below the opportunity cost of capital). In fact, the results of this study suggest that society would benefit substantially from additional investment in public wheat breeding research. However, one cannot make any definitive statement about the size of the additional investment. This is because efficient allocation of a given amount of scarce public resources requires that the marginal rates of return be equalized across the full array of public investment opportunities. Unfortunately, marginal rates of return for other public investment opportunities are not readily available in Canada. Consequently, the issue of public research resource allocative efficiency must remain open until such time as other empirical studies become available.

Finally, in regard to the distribution of social benefits from public wheat breeding research activities, the results suggest that both producers and consumers should continue to contribute to the research investment costs. However, since producers

(most likely landowners) receive the greatest share, an examination of the relative research contributions of each group and possible re-alignment may be warranted.

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