The Benefits and Costs of Producer and Public Investments: Wheat Varietal R&D in Western Canada 1995 to 2020

Katarzyna Bolek-Callbeck and Richard Gray[1]

University of Saskatchewan

March 2022

[1] Katarzyna Bolek-Callbeck (PhD) is a Research Associate and Richard Gray (PhD) is a Professor of Agricultural Economics at the University of Saskatchewan. Please email correspondence to Richard.Gray@usask.ca.

Executive Summary

This study was undertaken as a part of a levy review commissioned by the Saskatchewan Wheat Development Commission (Sask Wheat) for the purpose of estimating the benefits and costs of producer investments in wheat varietal development in Western Canada. Initiated with the Western Grains Research Foundation (WGRF) in 1994, Western Canada now has 27 years of experience with producer-funded, producer-controlled, investments in varietal research and development (R&D). This long legacy of varietal R&D can give a clear picture of the return on investment, even when benefits are spread over a few decades.

Varietal development in Western Canada has been dominated by public breeders in Agriculture and Agri-Food Canada (AAFC) and universities. Through breeding agreements producers have funded about 46% of the varietal R&D, with the remainder of investment coming from public dollars. In this study, we examine the benefits of past producer and public investments in wheat varietal development from 1994 to 2020. Given the similarity between this historical funding and the current structure of varietal R&D, our results should be indicative of the expected return from the ongoing producer-funded investments in wheat varietal R&D for Western Canada.

A benefit/cost analysis is used to compare benefits generated by the investments in varietal R&D to the costs of producer investments. This study adopts a similar methodology to the studies by Scott et al. (2005) and Gray, Nagy and Guzel (2012). It can be considered an update to earlier studies with the benefit of more years of data.

The timeline for the analysis covers the producer investments from 1995 to 2020 and includes foreseeable benefits to 2049. The lag that exists between the investment in R&D and the registration of new varieties is accounted for by starting the benefits stream in 2005. We also reasonably assume benefits to the investments in R&D over the years 1995-2020 will continue for ten years into the forecast period as new varieties are released and the developed genetics are used in those subsequent varieties.

We make a number of choices to provide a conservative and robust estimate of the returns on investment in varietal R&D. In our benefit stream we only include relative yield increases derived from variety performance trials weighted by the area of each variety grown by producers in each year. We do not include the value of other variety characteristics, including improved disease resistance, sawfly resistance, midge tolerance, or lodging resistance. Also, on the benefit side, we only include CWRS and durum wheat varieties, which jointly make up about 90% of the area, while on the cost side we include the costs of varietal R&D for all classes of wheat. Producers have supported 46% of the varietal development costs and we only attribute 46% of the yield gain to these investments despite the matching nature of many of these investments.

The estimated annual costs of varietal R&D investments from 1995 to 2020 and the resulting benefits from 2004 to 2049 are shown in Figure 7. The producer-funded investment costs at less than 0.5% of gross sales are dwarfed by the yield benefits, which after a 10-year delay accumulate about 1% of gross sales per year between 2004 and 2020. For the 2022 to 2029 forecast period, even if producer funding was terminated, we anticipate yield would continue to increase for a decade as genetics already in the pipeline would be commercialized and producers would continue to adopt the latest varieties. After 2029, we assume the impact of the past investments depreciate at 5% per year.

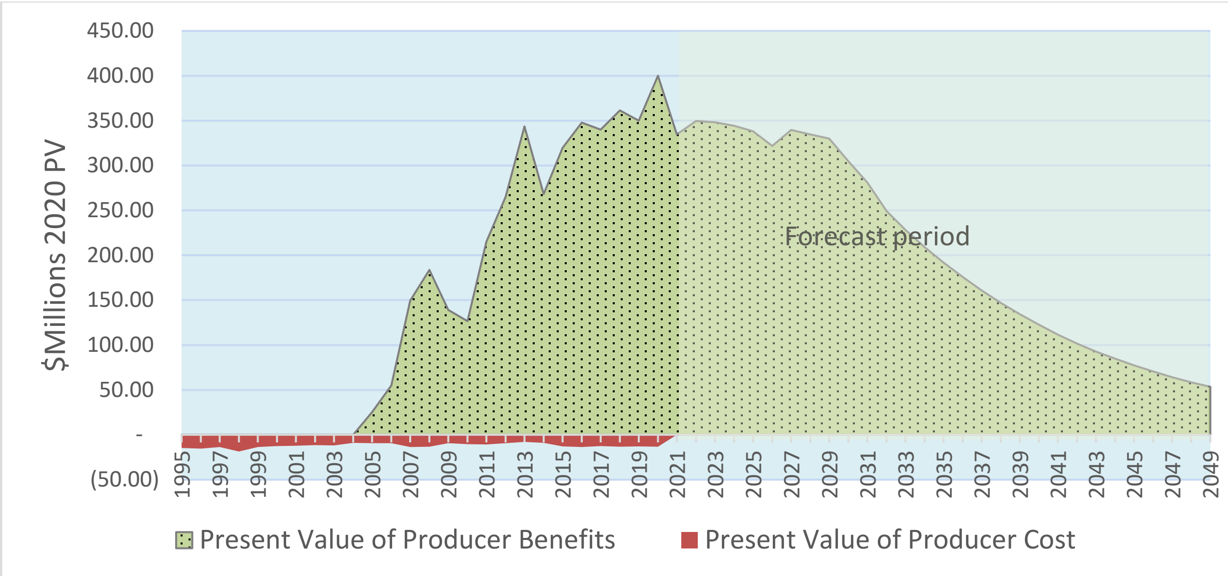

Figure7: Benefits and Costs of producer investments in Western Canadian wheat breeding from 1995 to 2020. Source: As calculated

Total varietal R&D costs over the 26-year period have a total present value of $685 million. The resulting varietal improvement has produced a stream of anticipated benefits with a total present value of $23.8 billion, with a remarkable overall 34.8 to 1 benefit cost ratio (B/C). This implies that each $1 of investment on average provides producers $34.8 in benefits, even after accounting for the time value of money.

Within this larger total, producer-funded investments between 1995 and 2020 were $314.6 million. Given the incidence of the check-offs, the producer share of these costs was $303 million. As reported, these producer-funded investments generated benefits with a present value of $9.85 billion, a remarkable 32.6 to 1 B/C ratio.

The producers' B/C of 32.6 to 1 indicates an extremely good investment for producers. For every $1 that producers' commissions and the WGRF invested in wheat breeding, they receive $32.6 back, even after the long research lags and the time value of money is accounted for. The internal rate of return is also extremely high relative to most investments. It is equivalent to having a bank saving account that earns 33.1% interest or nearly doubles in value every two years. Notably, if the producers also include the benefits from the taxpayer funded portion, their B/C ratio increases to $70.9 for every $1 dollar they invest.

Finally, it is worth noting that both foreign and Canadian consumers also reap significant benefits from Western Canadian wheat varietal R&D. Taking the small international price effects into account, consumers of Canadian wheat (mostly foreign) have also gained from Canadian wheat varietal R&D. Through the price effects of the levy, these consumers have also indirectly contributed a small amount to varietal R&D. Canadian taxpayers and Canadian wheat producers are reaping returns while helping to address global food security.

The taxpayer investments of $370.6 million in 2020 Present Value (PV) have also generated a very high rate of benefit to cost ratio increasing the gross value of wheat production by $12.9 billion dollars with an increase of $11.8 billion in benefits occurring in Canada.

Table 1 The Estimated Benefits and Costs of Producer and Public Investments in wheat breeding 1995- 2020

		Levy-funded varietal R&D	Taxpayer-funded varietal R&D	Total wheat varietal R&D
Costs $ million Present Value 2020$	Canadian producers	**302.6**	0	302.6
	Foreign consumers	10.16	0	10.16
	Canadian consumers	1.79	0	1.79
	Canadian taxpayers	0	370.6	370.6
	Total world	314.6	370.6	685.1
Benefits* $ million PV 2020$	Canadian producers	**9,851**	11,605	21,457
	Foreign consumers	930	1,096	2,026
	Canadian consumers	164	193	358
	Canadian benefits	10,015	11,799	21,814
	Total world	10,946	12.895	23,841
B/C Ratio	Canadian producers	**32.6**	infinite	70.9
	Canadian consumers	91.6	infinite	199.5
	Foreign consumers	91.6	infinite	199.5
	Canadian	infinite	31.8	32.3
	World	34.8	34.8	34.8

Source: Authors calculations

Policy implications

1. Given large benefit/cost ratios and exceptionally high rates of return to producer investment in public varietal R&D, the provincial commissions and WGRF should maximize the opportunity to invest more in varietal R&D.

2. A present value of the $370 million in taxpayer investments results in Canadian benefits exceeding $11.8 billion dollars or a 31.8 to 1 B/C ratio. (The return to taxpayers is even higher with the matching producer-funded support for AAFC breeding programs.) Assuming that the benefits created are taxed at greater than a 3% rate, these large benefit/cost ratios for public investments in wheat varietal R&D suggest the taxpayer investments create enough additional tax revenue to easily offset the taxpayer costs. As such it would be in the direct interest of all taxpayers to invest more in these high return activities.

3. While funding is important, the current institutional arrangements of producer-supported public breeding programs are responsible for generating the high rates of return. This suggests these breeding programs should be supported by all parties with the aim of enhancing capacity and sustaining these effective relationships over time.

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The Benefits and Costs of Producer and Public Investments: Wheat Varietal R&D in Western Canada 1995 to 2020

Katarzyna Bolek-Callbeck and Richard Gray

Introduction

Western Canada now has 27 years of experience with producer-funded, producer-controlled investments in public cereal breeding programs.[3] This is fortunate, because this long legacy of past breeding activity can give a clear picture of the return on investment even if benefits are spread over a few decades. In this study, we examine the track record of these past investments to assess the expected return from the ongoing producer-funded investments in wheat breeding in Western Canada. This report can be considered an update to earlier studies by Scott et al. (2005), and Gray, Nagy and Guzel (2012).

This study was commissioned and undertaken as part of a larger levy review for the Saskatchewan Wheat Development Commission (Sask Wheat). Given the joint funding of most breeding investments and the high level of cooperation among wheat breeders, we felt analysing the returns across Western Canada would give the most accurate estimate of the Benefits and Costs of producer-funded wheat breeding in Western Canada. Unlike the earlier studies, which focused on WGRF investments in both wheat and barley breeding, this study provides an overall return to producer directed investment in wheat breeding only and includes the significant investments from the Alberta Wheat Commission (AWC), the Saskatchewan Wheat Development Commission (SWDC), the Manitoba Crop Alliance (MCA), the Saskatchewan Winter Cereals Development Commission (SWCDC), and the Western Grains Research Foundation (WGRF).

Methodology

To estimate the return of past investment in wheat breeding development, the factual situation (what actually occurred) has to be compared to a counterfactual situation where investments were not made. The counterfactual is the hypothetical situation that would have existed if there were no funding in breeding and the development of wheat in Western Canada. For this counterfactual situation we assume the yield gains from the adoption of the new wheat variety programs would not have occurred without the producer supported public breeding effort. The gross annual research benefit approach (Alston et al., 1995) used in this analysis is similar to one used in the assessments of the rate of return to the WGRF investment by Scott et al. (2005), and Gray et al. (2012).

Cost and Benefit Periods

The cost period in this study covers the years 1995 to 2020, the period of history when check-offs on wheat have been invested in supporting public wheat breeding in Western Canada.

[3] The Western Grains Research Foundation introduced wheat and barley levies to support public breeding programs in 1994.

The benefits period in this study covers the years 2005 to 2049. The benefits period does not coincide with the cost period of varietal development because of the lag between the investment in varietal research and the release of a variety and subsequent adoption by growers. In a typical breeding program, wheat varieties take approximately ten years from first cross to first commercial planting of the new variety. It then takes several years for producers to fully adopt a new variety, and even longer until they have dis-adopted a variety. Even after a variety has been dis-adopted, the genetics of successful varieties are bred into subsequent varieties. For instance, successful Marquis wheat, bred in 1905, is part of the pedigree of every CWRS wheat variety grown today. Given the anticipated long benefit period, this study includes realized benefits from 2005 to 2021 and anticipated from 2022 to 2049. In this future period, we assess benefits from producer-funded varieties and account for recently released varieties and varieties that will result from producer funding to date.

Recognising the typical time from first cross time to commercial variety release, our estimated benefits start in 2005, giving the benefits a 10-year lag from the initial investment in wheat breeding in 1995. Beginning in 2005, the actual adoption of new varieties and yield performance indexes are used to calculate the cumulative gross annual research benefits, which are then used to calculate producer, consumer, and total benefits in each year from 2005 to 2020. From 2021 to 2029 we assume recently released varieties will continue to be adopted, consistent with earlier observed adoption patterns. For the years 2030 to 2049 we assume these varieties will contribute to the germplasm of future varieties, with their economic impact depreciating at a rate of 5% per year in 2030 and after[4].

Adjusting for Inflation and the Discount Rate

We adjusted the streams of benefit and costs for inflation using the consumer price index (CPI) to arrive at constant 2020 dollars. To reflect the time value of money we use a real discount rate of 5% in our present value calculation, which approximates producers' interest cost of money (Gray et al., 2012).

Calculating a Benefit/Cost Ratio and an Internal Rate of Return

Once the costs of breeding investment and the benefits of breeding investment are calculated and put into 2020 present value, we calculate a benefit cost ratio (B/C) and an internal rate of return (IRR). We calculate a B/C for producers reflecting only their benefits and their cost, and a general public benefit cost ratio. The B/C indicates the ratio of the present value benefits received to the present value costs of the investment, accounting for the time value of money. A B/C greater than one (1) suggests an economic return on investment is greater than cost. The internal rate to return (IRR) represents the real (inflation adjusted) rate of return on the breeding investment. Values higher than the prevailing market interest rates for borrowing indicate a good investment.

[4] This rate of depreciation for specific traits is difficult to quantify. However, given that typically the best traits of elite varieties are bred into and retained in subsequent varieties, the actual depreciation rate may be less than 5% per year. We use 5% in an effort to be conservative.

Empirical Analysis and Results

The theoretical methodology described above is used to estimate the B/C ratios and the IRR due to the investment of producer funds into the wheat plant breeding programs in western Canada.

Measuring the Cost

For the years 1995 to 2012, the estimates of costs from the earlier WGRF study by Gray et al., (2012) are used with one modification. Given the lack of detailed expenditure data, Gray et al. estimated these expenditures based on the number of scientists engaged in wheat breeding and an estimated annual cost per scientist of $490,000 (2020 dollars) adjusted by CPI. Gray et al. applied these costs per scientist to 3 scientists in 1995, to 11 scientists in years 1996 to 2000, to14 scientists in years 2001 to 2004, to 15.88 scientists in years 2005-2009 and to 15.38 scientists in years 2010 and 2011 so as to estimate the total investment in varietal R&D. Given that we are analysing all public breeding investment, and it is unlikely that the number of breeding related scientists increased from only 3 scientists in 1995 to 11 scientists in 1996, we use 11 scientists in 1995 to be sure we are not underestimating costs.

For years 2013-2020, annual expenditures for wheat breeding and germplasm screening were used to represent the costs associated with development of the new wheat varieties (Germplasm Screening/Breeding plus Genomics/Tools). WGRF, SWDC, AWC, MCA and SWCDC were very helpful in assembling this comprehensive expenditure data. To our knowledge this is the first time to conduct an analysis with such comprehensive investment data for Western Canada. It is worth noting these varietal R&D expenditures are only the reported projects, core funding, and breeding related costs, while fixed costs such as research infrastructure are not included. Assuming that the reported expenditures are essential for breeding, these omitted fixed costs do not impact the producer return or the reported expenditures. Given these public breeding programs are fully reliant on the varietal R&D costs that we report, the breeding outcomes can be attributed to the investments.

As shown in *Figure 1*, public and producer-funded wheat breeding real expenditures have increased since 1995, with approximately double the level of the investment occurring after 2015 and the establishment of provincial wheat commissions.

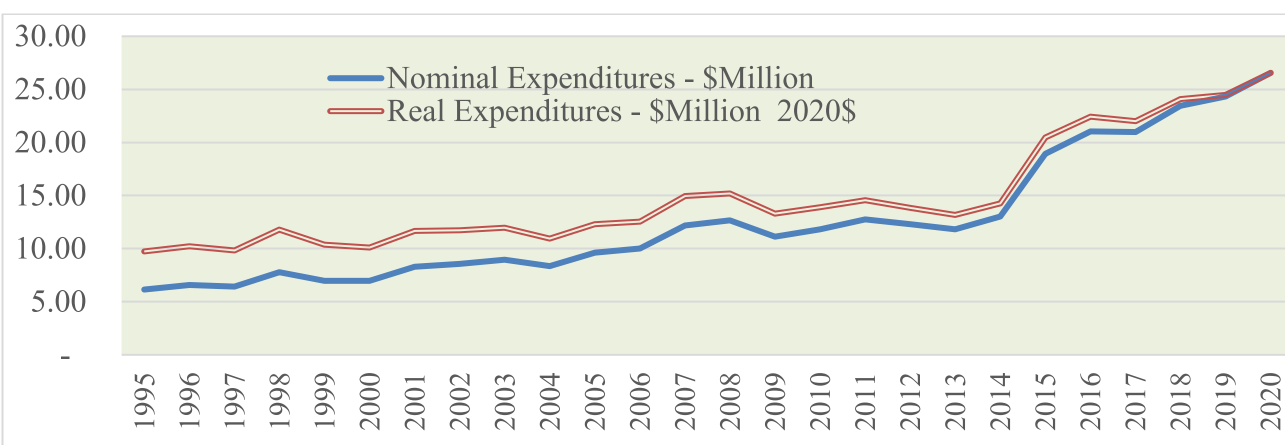

Figure 1: Estimated annual public and producer wheat breeding expenditures 1995-2020
Source: Please see text above

Estimating the Incidence of the Levy

Like other sales taxes, the levy, or check-off, drives a small wedge between the price received by the producer and the price paid by the grain buyer. Consistent with the methodology employed in Gray et al. 2012, we use the FAPRI estimates of Canadian wheat demand elasticity of 10 and a supply elasticity of 0.4. Given these elasticities, producers bear 96.2% of the levy cost while consumers bear 3.8 %. Of the consumer share, domestic consumers who make up 15% of the demand for Canadian wheat bear 15% with the remaining 85% paid by foreign consumers.

Measuring the Benefits of Improved Varieties

From 2005 onward we assume producers benefit from improved wheat genetics by adopting higher yielding wheat varieties. Every commercial wheat variety is subject to regional variety performance trials which assess the relative yield performance of each new variety relative to a check variety of wheat, reported as yield index. For instance, if a new variety is assigned a yield index of 110, it was 10% higher yielding than the check variety in randomized plot yield trials. With knowledge of the area of each wheat variety adopted by producers, we are able to calculate a weighted average yield index for producers in any given year in each province. To be conservative in our estimate of benefits we consider only the indexed yield improvements of newer varieties and do not consider the value of other traits such as insect resistance, yield stability, improved disease resistance etc.[5] For our 2005 to 2020 benefit period we find a genetic yield gain of about 1% per year, which is about one half of the overall gain experienced by Western Canadian wheat producers during the same period of time.

The impact of the genetically improved varieties on farm yields is reflected in the change in the average yield index of the varieties grown by producers over time. Benefits arise as new varieties developed through producer-funded breeding agreements are adopted by producers in Western Canada.

In this study varietal genetic gain is measured as an increase in weighted average yield index over the weighted average yield index that existed in 2004. The difference in the average yield index over time is then applied to gross value of wheat production in each year to quantify the economic value of new varieties to producers. For our 2004 to 2020 benefit period, we find a genetic yield gain of about 1% per year, which is about one half of the overall gain experienced by Western Canadian wheat producers during the same period of time.

While we explored the option of reporting results for many classes of wheat, it quickly became apparent that CWRS and Durum wheat collectively make up a 90% market share and that if we accurately estimate and sum of return for these two classes of wheat, it will conservatively approximate the overall benefits from all wheat variety development. Because we include the breeding investments for all classes of wheat in the denominator of our B/C ratio, this ratio will also provide a conservative estimate of the overall return.

[5] In variety performance trials pest and diseases pressure are carefully controlled through pesticide application so the reported relative yield trials will tend to underestimate the benefits of disease and pest resistance.

Yield increases

As presented in Figures 2 and 3, CWRS and Durum wheat varieties grown by Saskatchewan producers in 2019 yield about 11.7% to 16.7% higher than the area weighted average of varieties grown in 2004.[6] As the most recent varieties follow the typical adoption curves, this yield increase relative to 2004 levels will reach 22% and 28% respectively by 2029. This observed and forecasted percent yield increase from 2004 levels is reported in Table A1 in the Appendix and is shown below in Figures 2 and 3.

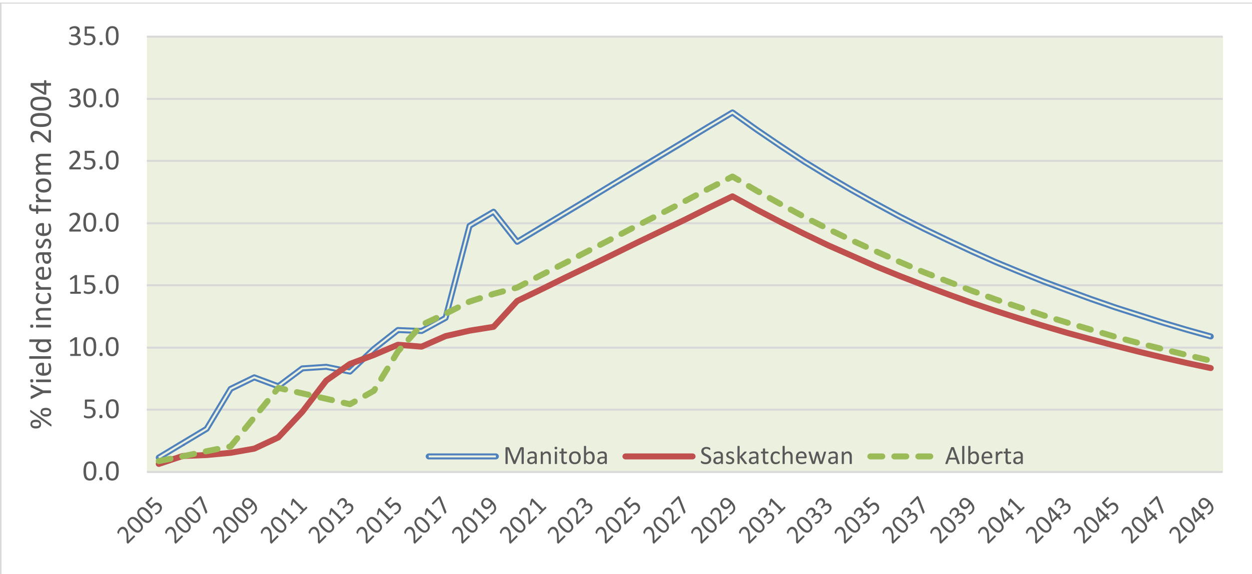

Figure 2: The Increase in Area Weighted Yield Index for CWRS Wheat by Province 2004-2049
Source: Averages are calculated from Variety Performance Yield Indexes weighted by production area of each variety

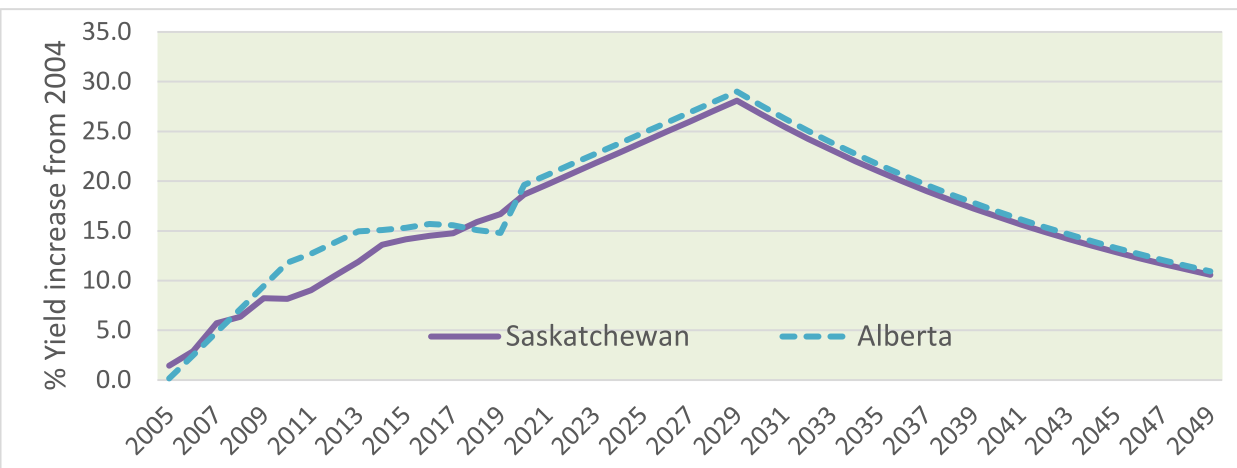

Figure 3: The Increase in Area Weighted Yield Index for Durum Wheat by Province 2004-2049
Source: Average Variety Performance Yield Indexes weighted by production area of each variety

[6] It should be noted that the average CWRS wheat yields increased by 40% between 2005 and 2020, so about 1/2 of increase in farms yields can be attributed to improved varieties, with the remainder attributed to increased inputs, better agronomics and perhaps weather.

Figures 4 and 5 apply these percentage yield index increases to realised production in each year to calculate the additional quantity of wheat grown in Western Canada since 2004 that can reasonably be attributed to the 1995-2020 breeding efforts.

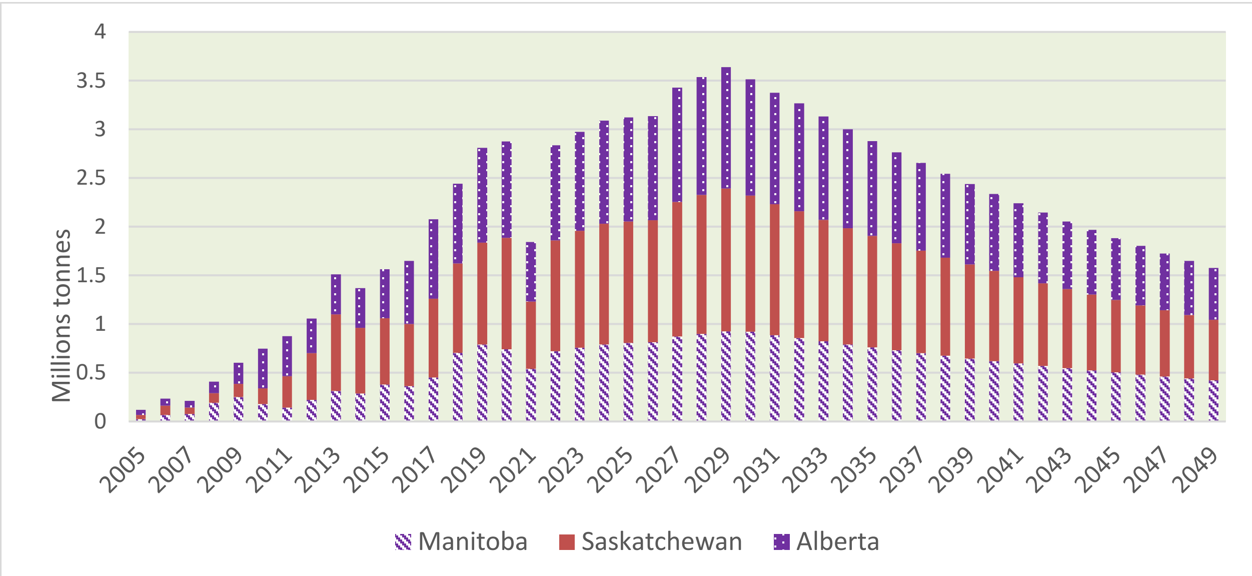

Figure 4: The Estimated Increase in Quantity of CWRS Production 2005 to 2050
Source: Authors' calculations

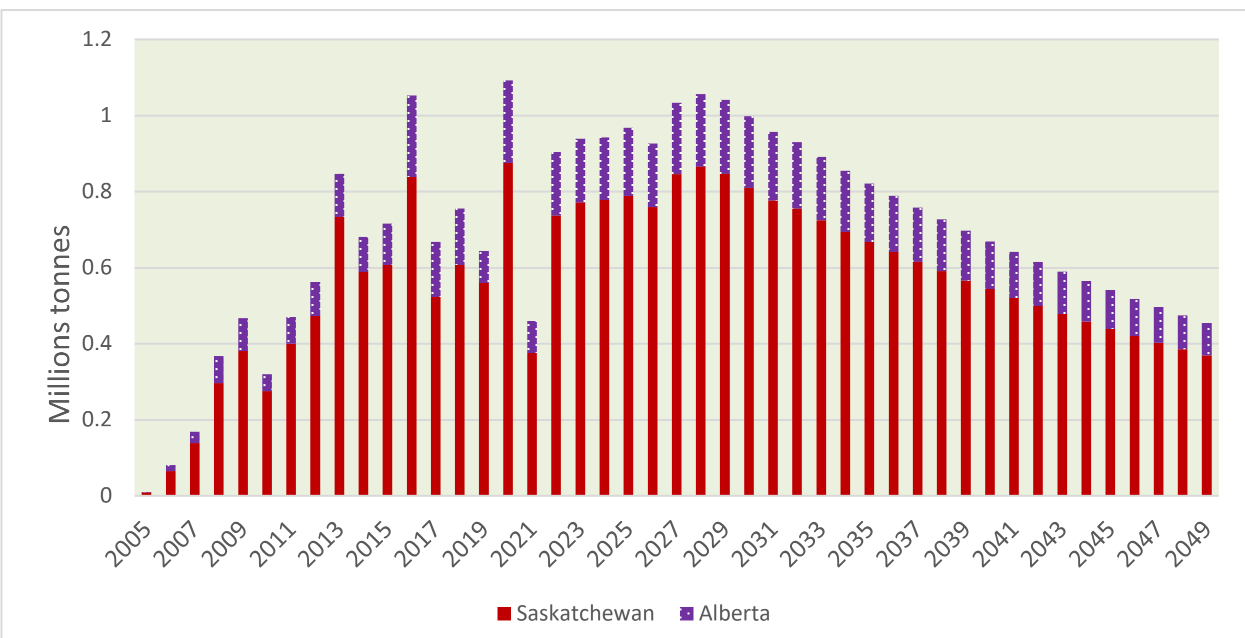

Figure 5: The Estimated Increase in Quantity of Durum Wheat Production 2005 to 2050
Source: Authors' calculations

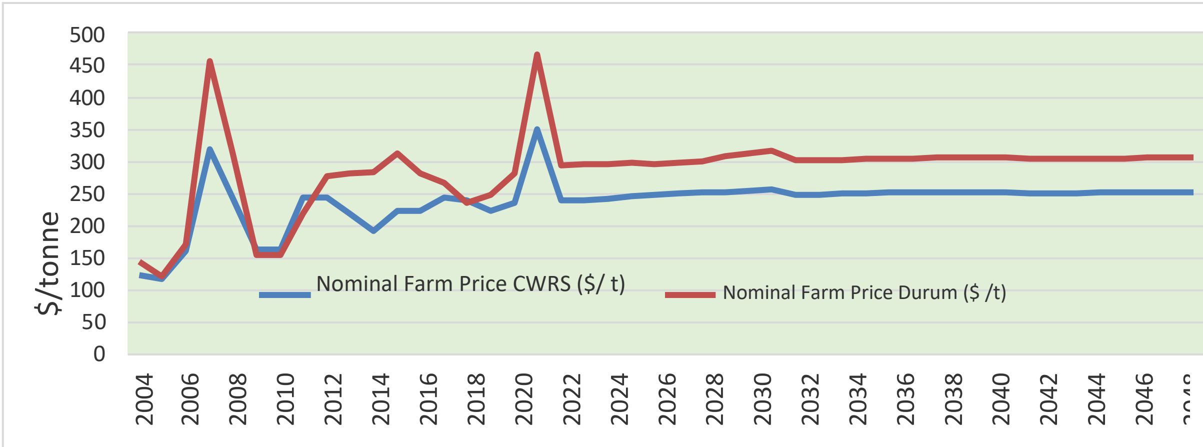

Figure 6: Average CWRS and Durum Wheat Prices received in Saskatchewan 2004 to 2049
Source: Statistics Canada, Table 001-0010

Multiplying this additional wheat production by the average Saskatchewan farm prices (*Figure 6*) and adjusting for market price impacts provides a conservative estimate of the producer benefits of these breeding investments.

The estimated annual costs of varietal R&D investments from 1995 to 2020 and the resulting benefits from 2005 to 2049 are shown in Figure 7. The producer-funded investment costs at less than 0.5% of gross sales, are dwarfed by the yield benefits, which after a 10-year delay accumulate at about 1% of gross sales per year between 2005 and 2020. For the 2022 to 2029 forecast period, we recognise even if producer funding was terminated, yield would continue to increase for a decade as genetics already in the pipeline would be commercialized and producers would continue to adopt the latest varieties. After 2029, we assume the impact of the past investments depreciate at 5% per year.

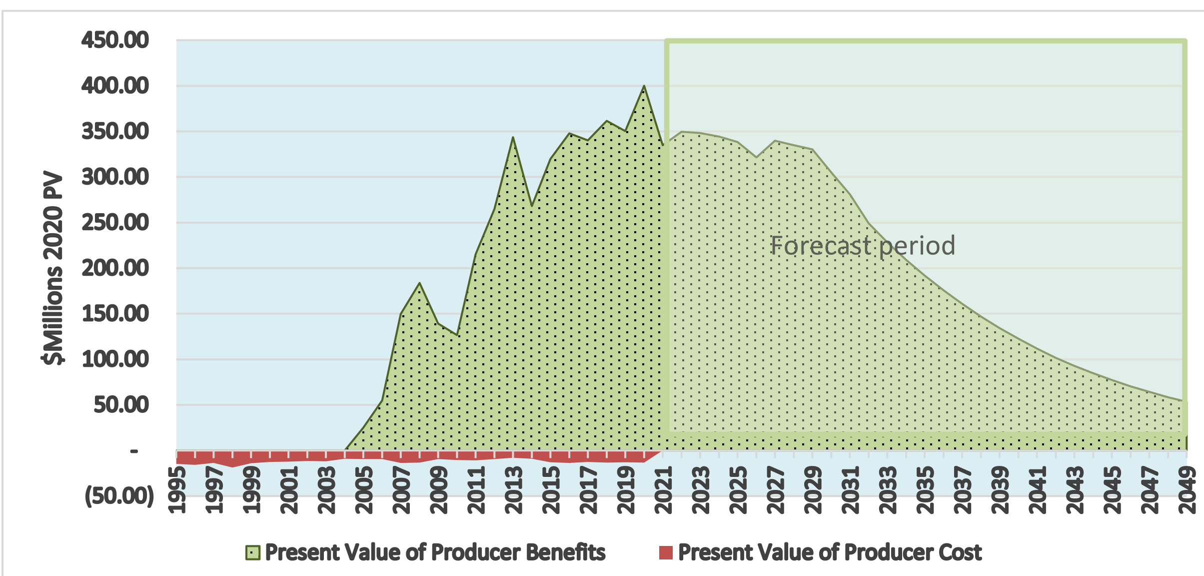

Figure 7: Benefits and Costs of producer investments in Western Canadian Wheat Varietal R&D from 1995 to 2020
Source: Authors calculation (Please see the Appendix for details)

Finally, comparing the producers' benefits to the present value of their share of the breeding costs allows a straightforward, somewhat conservative, estimate of the B/C ratio and internal rate of return. A summary of the key B/C results is numerically presented in Table 1. The third column of the table reports the costs and benefits from the producer-funded portion of the varietal R&D. As noted above, the costs of the levy are partially paid for by consumers through higher prices. As evident in the benefits, consumers also share a portion of the benefits of higher yield through lower prices. The fourth column of Table 1 reports the costs and benefits from the public funded portion of the varietal R&D. The fifth column of Table 1 is the summation of impacts of producer-funded and public investments reported in columns 3 and 4 respectively.

Table 1: Benefits and Costs of Producer and Public Investments in Wheat Varietal R&D 1995 to 2020

		Levy-funded varietal R&D	Taxpayer-funded varietal R&D	Total wheat varietal R&D
Costs $ million PV 2020$	Canadian producers	302.6	0	302.6
	Foreign consumers	10.16	0	10.16
	Canadian consumers	1.79	0	1.79
	Canadian taxpayers	0	370.6	370.6
	Total world	314.6	370.6	685.1
Benefits* $ million PV 2020$	Canadian producers	9,851	11,605	21,457
	Foreign consumers	930	1,096	2,026
	Canadian consumers	164	193	358
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	Total world	10,946	12.895	23,841
B/C Ratio	Canadian producers	32.6	infinite	70.9
	Canadian consumers	91.6	infinite	199.5
	Foreign consumers	91.6	infinite	199.5
	Canadian	infinite	31.8	32.3
	World	34.8	34.8	34.8

Source: Authors calculation (Please see the Appendix for details)

Total varietal R&D costs over the 26-year period have a total present value of $685.1 million. The resulting varietal improvement has produced a stream of anticipated benefits with a total world present value of $23.8 billion, with a remarkable overall 34.8 to 1 benefit cost ratio. This implies that each $1 of investment on average provides producers $34.8 in benefits, even after accounting for the time value of money.

Within this larger total, producer-funded investments between 1995 and 2020 were $314.6 million. Given the incidence of the check-offs, the producer share of these costs were $303 million. As reported, these producer-funded investments generated benefits with a present value of $9.85 billion. These results represent a remarkable 32.6 to 1 B/C ratio

Table 2: The Estimated Internal Rate of Return of Producer and Public Investments in Wheat Varietal R&D 1995 to 2020

	Costs 2020 Present Value *($ Million)*	Benefits 2020 Present Value *($ Million)*	Benefit/Cost Ratio	Internal Rate of Return
Producer gross annual research benefits	302.6	9,851	32.6	33.1%
Total ROI from producer-funded research	314.55	10,946	34.8	33.7%

Source: Authors calculations (Please see page A13).

The producers' B/C of 32.6 to 1 indicates an extremely good investment for producers. For every $1 that producer commissions and the WGRF invested in wheat breeding, they receive $32.6 back, even after the long research lags and the time value of money is accounted for. The internal rate of return is also extremely high relative to most investments. It is equivalent to having a bank savings account that earns 33.1% interest or nearly doubles in value about every two years. Notably, if the producers also include the benefits from the taxpayer funded portion, their B/C ratio increases to $70.9 for every $1 dollar they invest.

Finally, it is worth noting that both foreign and Canadian consumers also reap some benefits from Western Canadian wheat varietal R&D. Taking the small international price effects into account, consumers of Canadian wheat (mostly foreign) have also gained from Canadian wheat varietal R&D. Through the price effects of the levy, these consumers have also indirectly contributed a small amount to varietal R&D. Canadian taxpayers and Canadian wheat producers are reaping returns while helping to address global food security.

The taxpayer investments of $370.6 million (2020 PV) have also generated a very high rate of benefit to cost ratio increasing the gross value of wheat production by $12.9 billion with an increase of $11.8 billion in benefits occurring in Canada.

Sensitivity Analysis

In our estimates, we deliberately strived to produce a conservative and robust estimate of the returns to producer and public varietal R&D investment. As such, there were many possibilities to explore our conservative assumptions in a sensitivity analysis. For example, we could approximate the benefits to wheat varieties that we excluded in our benefit calculations, or we could include economic value for improved pest resistance etc. Anticipating this additional analysis would only increase our high estimated returns, we therefore did not explore this further.

One assumption we made in our analysis was that the yield trend we found in the provincial weighted varietal indexes established over the 2005 to 2019 period would continue "on trend" until 2029 even without continued public and producer investment. While some of this trend would certainly continue without additional investment, the impact could also certainly diminish.[6] To test how sensitive our results were to this assumption, we made an alternative assumption and examined the results. We assumed that rather than continuing on trend for the ten-year period after the funding period, the trend yield increase would decrease linearly by 10% each year, reaching zero growth by 2029. These modified trend yield index projections and results are reported in Figure 8.

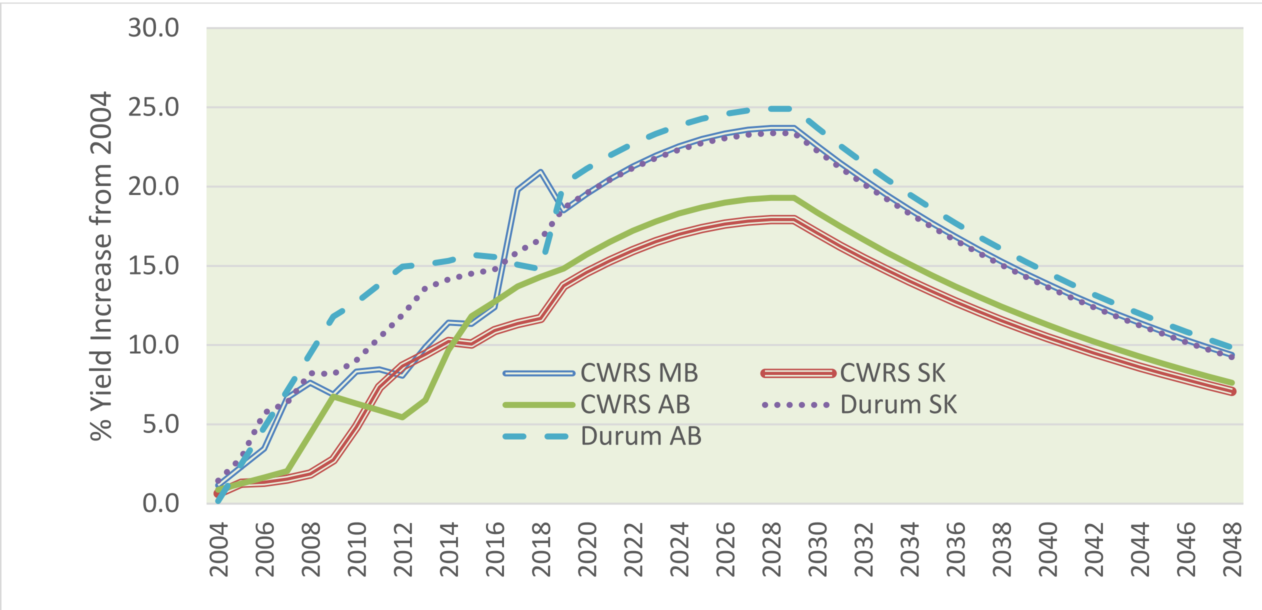

Figure 8: The Yield Index for Wheat 2004-2049 with Linearly Declining Growth Impact

As evident in Table 3, this very conservative future yield growth scenario had a very modest impact on the results, only decreasing the overall B/C ratio from 34.8 to 1 (Table 1) to 32.8 to 1. Even with the assumption of quickly declining benefits, the B/C ratio to producer investment remains extremely attractive with $30.7 in return for every $1 invested.

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[6] It could be argued that if varietal R&D investments have some impact on the yield index in less than 10 years, then some of the yield gain prior 2004 should also be included in this scenario. Again, in an effort to be very conservative, we did not include these benefits.

Table 3: The Estimated Benefits and Costs of Producer and Public Investments in Wheat Breeding 1995 to 2020 when benefits decline after 2020

		Producer-funded varietal R&D	Taxpayer-funded varietal R&D	Total wheat varietal R&D
Costs $ million PV 2020$	Canadian producers	302.60	0	302.60
	Foreign consumers	10.16	0	10.16
	Canadian consumers	1.79	0	1.79
	Canadian taxpayers	0	370.56	370.56
	Total world	314.55	370.6	685.1
Benefits $ million PV 2020$	Canadian producers	9,290	10,944	20,234
	Foreign consumers	877	1,034	1,911
	Canadian consumers	155	182	337
	Canadian benefits	9,445	11,126	20,571
	Total world	10,322	12,160	22,482
B/C Ratio	Canadian producers	30.7	infinite	66.87
	Canadian consumers	86.41	infinite	188.09
	Foreign consumers	86.41	infinite	188.09
	Canadian	infinite	30.0	30.5
	World	32.84	32.81	32.82

Source: See text

Study Limitations

While our study is limited in scope, we are confident that a more comprehensive study would not alter our general findings of very large benefit cost ratios and high rates of return to both producer and public investments in wheat research. The conclusions would not change because varietal R&D makes up the majority of producer-directed investment and overall public and producer benefits are already dwarfed by our conservative estimates of wheat varietal R&D benefits.

We deliberately limited the scope of our study to compare the costs incurred for all classes of wheat varietal R&D to a conservative estimate of the realised and anticipated benefits of these investments for CWRS and durum wheat, which collectively make up about 90% of the wheat area. An expanded study of varietal R&D could include the benefits for all wheat classes of wheat and could include benefits of increased disease resistance, insect resistance, and agronomic traits which have also certainly contributed to improved variety performance and economic returns. An expanded study of overall producer investment could also examine producer and public investments in agronomic research, policy research, and market development activities.

Policy Implications

The results of this analysis offer several important policy implications:

1. Given large benefit/cost ratios and exceptionally high rates of return to producer investment in public varietal R&D, the provincial commissions and WGRF should maximize the opportunity to invest more in varietal R&D.

2. A present value of the $370 million in taxpayer investment results in Canadian benefits reaching $11.8 billion dollars or a 31.8 to 1 B/C ratio. (The return to taxpayers is even higher with the matching producer-funded support for AAFC breeding programs.) Assuming that the benefits created are taxed at greater than a 3% rate, these large benefit/cost ratios for public investments in wheat varietal R&D suggest the taxpayer investments create enough additional tax revenue to easily offset the taxpayer costs. As such it would be in the direct interest of all taxpayers to invest more in these high return activities.

3. While funding is important, the current institutional arrangements of producer-supported public breeding programs are responsible for generating the high rates of return. This suggests these breeding programs should be supported by all parties with the aim of enhancing capacity and sustaining these effective relationships over time.

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Data and Mathematical Appendix

Estimating Yield Increases

This analysis begins with the relative performance of CWRS and Durum wheat varieties grown in Manitoba, Saskatchewan and Alberta. Each commercialized wheat variety is subject to several years of performance trials, which calculates a yield index for each variety relative to a check variety. A sample of performance trial report is provided in Table A1.

1. $$y_i = \frac{\mathbb{Y}_i}{\mathbb{Y}_{Check\ variety}} \cdot 100.$$ For example, for AAC Brandon $y_i = 106$

Table A1: An example of the performance trial report

Wheat

Main Characteristics of Varieties

Category and Variety	Years Tested	------ Yield (%) ------ Area 1 & 2	Area 3 & 4	Irrigation	Protein	---- Resistance To[2] ---- Lodging	Sprouting	Stem Rust	Leaf Rust	Stripe Rust	Loose Smut	Bunt	Leaf Spot	FHB
CWRS[1]		--- Relative to Carberry ---												
Carberry	6	100	100	100	14.5	VG	F	MR	R	MR	MR	R	MS	MR
CDC Adamant VB	4	107	113	---	-0.2	P	F	R	I	MS	S	S	MS	I
AAC Alida VB	3	106	108	---	-0.2	VG	VG	R	R	MR	R	I	MS	MR
Bolles	1	107	106	---	+0.4	VG	---	MR	R	MR	---	S	---	I
CDC Bradwell	5	101	108	---	-0.2	VG	F	MR	R	MS	MR	R	MS	I
AAC Brandon	5	106	106	---	-0.4	G	P	R	R	MR	MR	S	I	MR
AAC Broadacres VB	1	111	112	---	-0.6	VG	F	R	R	MR	---	MR	---	I
AAC Cameron VB	5	108	118	---	-0.6	F	F	MR	MR	S	S	R	I	I

Source: Page 12 of Varieties of Grain Crops 2020 (Saskatchewan Agriculture- https://saskseed.ca/seed-guides)

The area-weighted average yield index in year *t*, Y_t is yield index of each variety weighted by its share of seeded area for the wheat class or:

2. $$Y_t = \sum_i y_i \frac{A_{it}}{\sum_i A_{it}},$$

where A_{it} is the area of variety *i* in year *t*. The area-weighted average yield index in each year was calculated for CWRS in Manitoba (MB), Saskatchewan (SK) and Alberta (AB), and for Durum in Saskatchewan and Alberta.

As described in the report, because of the dominance of wheat varieties that were produced from levy-funded breeding programs, we consider the weighted average yield that existed in 2004 as our counterfactual yield index that would have existed without the varietal R&D investments[1]. The benefits of the varietal R&D investments are therefore the annual percentage increase in weighted average yield index from 2004, $\%\Delta Y_t$. This percentage genetic yield is equal to weighted average yield index in year t, Y_t minus area-weighted average yield index $Y_{2004,}$ converted to percentage change or:

3. $$\%\Delta Y_t = \left(\frac{Y_t - Y_{2004}}{Y_{2004}}\right) \times 100.$$

The annual percentage increase in weighted average yield index from 2004, $\%\Delta Y_t$, was calculated for CWRS in Manitoba (MB), Saskatchewan (SK) and Alberta (AB), and for Durum in Saskatchewan and Alberta. These are reported in Table A2. The $\%\Delta Y_t$ is a measure of the percentage increase in yield from 2004 due to development and adoption of improved wheat varieties.

[1] One could reasonably argue in the absence of these investment there would have been other varieties developed but these varieties would have also come with additional cost to producers. Furthermore, in the absence of breeding effort, yields would naturally decrease as disease and other pests overcome the resistance of older varieties.

*Table A2: Percentage Increase from 2004 in Weighted Average Yield Index by Wheat Class and Province**

	CWRS MB	CWRS SK	CWRS AB	Durum SK	Durum AB
2005	1.16	0.65	0.88	1.45	0.17
2006	2.31	1.29	1.27	2.89	2.48
2007	3.47	1.35	1.66	5.72	4.80
2008	6.68	1.55	2.05	6.37	7.12
2009	7.62	1.87	4.41	8.23	9.46
2010	6.88	2.76	6.76	8.17	11.80
2011	8.33	4.84	6.32	9.04	12.70
2012	8.47	7.34	5.88	10.47	13.83
2013	8.07	8.68	5.44	11.90	14.96
2014	9.89	9.42	6.54	13.60	15.09
2015	11.41	10.23	9.68	14.16	15.32
2016	11.35	10.08	11.83	14.51	15.70
2017	12.39	10.92	12.73	14.76	15.55
2018	19.80	11.36	13.70	15.88	15.07
2019	20.92	11.68	14.32	16.67	14.79
2020	18.50	13.75	14.83	18.65	19.61
2021	19.66	14.68	15.82	19.70	20.65
2022	20.81	15.62	16.81	20.75	21.70
2023	21.97	16.55	17.81	21.80	22.74
2024	23.13	17.49	18.80	22.85	23.78
2025	24.28	18.42	19.79	23.90	24.83
2026	25.44	19.36	20.78	24.94	25.87
2027	26.59	20.29	21.77	25.99	26.92
2028	27.75	21.23	22.76	27.04	27.96
2029	28.91	22.16	23.76	28.09	29.00
2030	27.53	21.11	22.62	26.75	27.62
2031	26.22	20.10	21.55	25.48	26.31
2032	24.97	19.15	20.52	24.27	25.05
2033	23.78	18.23	19.54	23.11	23.86
2034	22.65	17.37	18.61	22.01	22.72
2035	21.57	16.54	17.73	20.96	21.64
2036	20.54	15.75	16.88	19.96	20.61
2037	19.57	15.00	16.08	19.01	19.63
2038	18.63	14.29	15.31	18.11	18.70
2039	17.75	13.61	14.58	17.25	17.81
2040	16.90	12.96	13.89	16.42	16.96
2041	16.10	12.34	13.23	15.64	16.15
2042	15.33	11.75	12.60	14.90	15.38
2043	14.60	11.19	12.00	14.19	14.65
2044	13.91	10.66	11.43	13.51	13.95
2045	13.24	10.15	10.88	12.87	13.29
2046	12.61	9.67	10.36	12.26	12.65
2047	12.01	9.21	9.87	11.67	12.05
2048	11.44	8.77	9.40	11.12	11.48
2049	10.9	8.35	8.95	10.59	10.93

Sources: Crop Variety Guides 2005 – 2020.

See equation 3 above: $\%\Delta Y_t = \left[\left(\frac{Y_t}{Y_{2004}}\right) - 1\right] \times 100$

2005 to 2020 calculated from relative yield index of wheat varieties weighted area by area;
2021 to 2029 is forecast from 2005 -2019 trend;
2030 to 2049 forecast is 2029 forecast declining at 5% per year

Estimating the Value of Genetic gain

The gross economic value of these genetic gains can be approximated by applying $\%\Delta Y_t$ to the quantity of wheat that was produced in each year. More specifically, quantity of annual wheat production increase due to varietal improvement since 2004, ΔQ_t, can be approximated by multiplying the reported quantity of production in year *t* by the proportional increase in the $\frac{\%\Delta Y_t}{(100+\%\Delta Y_t)}$. For example, if Y_{2004} = 100 and Y_{2015} = 112 , then $\%\Delta Y_{2015}$ = 12, then multiplying the quantity of wheat production by $\frac{\%\Delta Y_t}{(100+\%\Delta Y_t)}, ie. \frac{12}{(100+12)}$ will be equal to the increase in production over the production that would have occurred with the 2004 yield index of 100, or more generally:

4. $$\Delta Q_t = Q_t \frac{\%\Delta Y_t}{(100+\%\Delta Y_t)}.$$

The Quantities of CWRS and Durum production 2005 to 2049 are in reported Table A3. A 5-year moving average is used to forecast production from 2020 to 2049. To estimate the *Gross Annual Research Benefit* in each year (*GARB$_t$*), the increase in production of wheat is multiplied by the nominal price of wheat P_t^n in each year *t*, or:

5. $$GB_t = \Delta Q_t \times P_t^n.$$

The nominal prices P_t^n for CWRS wheat and durum are reported in Table A4, for 2022 to 2049. We forecast prices using a ten-year moving average of previous prices. In the final column, the nominal gross value of additional production is reported as the sum of value of additional CWRS and durum wheat. This gross dollar value of the additional wheat produced in Western Canada is due to genetic varietal improvement.

*Table A3: 'Factual' and Forecast Factual CWRS and Durum Wheat Production Manitoba (MB), Saskatchewan (SK) and Alberta (AB) 2005 to 2049**

YEAR	CWRS MB	CWRS SK	CWRS AB	Durum SK	Durum AB
	Production (1,000 tonne)				
2005	1987	7090	5922	4878	1021
2006	2988	7403	5757	2689	657
2007	2281	4953	4319	3011	670
2008	3082	6273	5990	4442	1078
2009	3535	7403	5155	4406	993
2010	2790	5948	6442	2603	422
2011	1856	6982	6887	3552	621
2012	2852	7022	6396	3895	732
2013	4191	9849	7955	5634	871
2014	3198	7816	6635	4485	708
2015	3715	7321	5715	4572	817
2016	3544	6994	6124	6178	1584
2017	4090	8225	7220	3879	1083
2018	4272	8991	6789	4636	1134
2019	4567	9999	7772	4342	647
2020	4744	9467	7681	5211	1325
2021	3293	5389	4491	2146	485
2022	4193	8414	6791	4043	935
2023	4214	8452	6705	4076	905
2024	4202	8344	6688	3964	859
2025	4129	8013	6471	3888	902
2026	4006	7722	6229	3623	817
2027	4149	8189	6577	3919	884
2028	4140	8144	6534	3894	874
2029	4125	8083	6500	3857	867
2030	4110	8030	6462	3836	869
2031	4106	8034	6460	3826	862
2032	4126	8096	6507	3866	871
2033	4122	8077	6493	3856	869
2034	4118	8064	6484	3848	868
2035	4116	8060	6481	3846	868
2036	4118	8066	6485	3849	867
2037	4120	8073	6490	3853	868
2038	4119	8068	6487	3850	868
2039	4118	8066	6485	3849	868
2040	4118	8067	6486	3850	868
2041	4119	8068	6486	3850	868
2042	4119	8068	6487	3851	868
2043	4118	8068	6486	3850	868
2044	4118	8067	6486	3850	868
2045	4118	8068	6486	3850	868
2046	4119	8068	6486	3850	868
2047	4119	8068	6486	3850	868
2048	4118	8068	6486	3850	868
2049	4118	8068	6486	3850	868

Source: Statistics Canada (2005- 2021); 5-year Moving Average forecast 2022 to 2049

Table A4: Counterfactual Change in CWRS and Durum Wheat Production Manitoba (MB), Saskatchewan (SK) and Alberta (AB) 2005 to 2049 in the absence of 1995 -2020 R&D.

Year	CWRS MB	CWRS SK	CWRS AB	CWRS Total	Durum SK	Durum AB	Durum Total	CWRS Price	Durum Price	Total Value
1000 tonnes								$/t	$/t	$ Mil.
2005	23	46	51	120	70	2	71	118	122	23
2006	68	94	72	234	76	16	92	161	172	53
2007	76	66	70	213	163	31	194	319	456	156
2008	193	96	120	409	266	72	337	244	316	206
2009	250	136	218	604	335	86	421	164	156	164
2010	180	160	408	748	197	45	241	164	156	160
2011	143	323	410	875	294	70	364	244	219	294
2012	223	480	355	1058	369	89	458	245	277	386
2013	313	787	410	1510	599	113	713	219	281	530
2014	288	673	407	1368	537	93	630	193	284	443
2015	381	680	504	1565	567	108	675	223	312	560
2016	361	640	648	1649	783	215	998	224	281	650
2017	451	810	815	2076	499	146	645	243	266	677
2018	706	917	818	2442	635	149	784	241	237	773
2019	790	1045	974	2809	621	83	704	223	248	802
2020	741	1144	992	2877	819	217	1036	235	282	968
2021	541	690	613	1844	353	83	436	351	467	851
2022	722	1137	977	2837	695	167	861	240	294	933
2023	759	1200	1013	2973	729	168	897	239	295	976
2024	789	1242	1058	3090	737	165	902	241	297	1013
2025	807	1247	1069	3122	750	179	929	246	298	1045
2026	812	1252	1072	3137	723	168	891	248	297	1043
2027	872	1382	1176	3429	808	187	996	251	298	1157
2028	899	1426	1212	3537	829	191	1020	251	301	1197
2029	925	1466	1248	3639	846	195	1041	253	308	1239
2030	887	1400	1192	3479	810	188	998	256	314	1202
2031	853	1345	1145	3343	777	180	956	258	317	1164
2032	824	1301	1108	3233	755	175	930	248	302	1083
2033	792	1246	1061	3099	724	167	891	249	303	1042
2034	760	1193	1018	2971	694	161	855	250	303	1002
2035	730	1144	976	2850	667	154	821	251	304	965
2036	702	1098	937	2736	640	148	789	251	305	928
2037	674	1053	899	2626	616	143	758	252	305	893
2038	647	1009	861	2517	590	137	727	252	306	856
2039	621	966	825	2412	566	131	697	252	307	821
2040	595	925	791	2312	543	126	669	252	306	787
2041	571	886	758	2215	521	121	641	251	306	753
2042	547	849	726	2122	499	116	615	251	305	720
2043	525	812	695	2032	478	111	589	251	305	690
2044	503	777	665	1945	458	106	565	251	305	661
2045	482	744	637	1862	439	102	541	251	305	633
2046	461	711	609	1782	420	97	518	252	305	606
2047	442	680	583	1705	402	93	496	252	306	580
2048	423	651	557	1631	385	89	475	251	306	555
2049	405	622	533	1560	369	86	454	251	306	531

Source: As calculated by multiplied production each year (Table A3) by $\Delta Q_t = Q_t \frac{\%\Delta y_t}{(100+\%\Delta y_t)}$, where $\%\Delta y_t$ as reported in Table A2. (see equation 5)

To compare these benefits to the costs over multiple years, we must account for inflation and the time value of money. To account for inflation, all dollar values are to 2020 dollars using the consumer price index CPI, by multiplying by $\frac{CPI_{2020}}{CPI_t}$. This conversion is applied to all research investment costs and Gross Annual Research Benefits (GARB) in Columns *D, E, F* and *G* in Table A5.

To account for the time value of money we use a 5% real discount rate. We apply a discount factor equal to $\left(\frac{1}{1+.05}\right)^{(t-2020)}$, (Column *H*) to the real costs and real benefits reported in Table A5. These annual present value estimates are reported in Columns *I* and *J* or Table A5. The Total Present Value of Investment of $685 million appears in the last row of Column *I*. The Total of the Present Value of Gross Annual Research Benefits of $24.1 billion appears in the last row of Column *J*. These total costs and total gross benefits, while indicative of the total return on investment, need to be broken down to reflect the benefits and costs of various market participants.

While our primary interest is to estimate the producers' return to levy-funded varietal R&D investments, we are also interested in public varietal R&D investments, as they impact not only producers but also the domestic and foreign consumers of Western Canadian wheat. A summary of these results are reported in Table 3 of the report.

Table A5: Estimated Annual Costs and Benefits of 1995 -2020 Varietal R&D in Western Canada

Year	(A) [1] Levy R&D Inv. $Mil.	(B) [1] Gov't R&D Inv. $Mil.	(C) [2] CPI 2020 = 100	(D) [3] Levy R&D Inv. M2020$	(E) [3] Gov't R&D Inv. M2020$	(F) [3] Total[3] R&D Inv. M2020$	(G) [4] Total R&D Benefit M$2020	(H)[5] 2020 Disc. Factor @5%/yr	(I) [6] 2020PV R&D Inv. $Mil.	(J)[7] 2020PV R&D Benefit $Mil
1995	2.76	3.39	63.1	4.37	5.37	9.74		3.39	32.98	
1996	3.10	3.47	64.3	4.82	5.40	10.23		3.23	32.98	
1997	2.89	3.52	65.1	4.44	5.40	9.84		3.07	30.23	
1998	4.21	3.57	66.0	6.38	5.40	11.78		2.93	34.46	
1999	3.33	3.63	67.1	4.96	5.40	10.36		2.79	28.87	
2000	3.24	3.72	68.9	4.69	5.40	10.10		2.65	26.79	
2001	3.41	4.88	71.0	4.80	6.88	11.67		2.53	29.49	
2002	3.55	5.02	73.0	4.85	6.88	11.73		2.41	28.23	
2003	3.81	5.14	74.7	5.11	6.88	11.98		2.29	27.46	
2004	3.12	5.25	76.4	4.08	6.88	10.96		2.18	23.93	
2005	3.51	6.10	78.2	4.49	7.80	12.29	29	2.08	25.55	61
2006	3.78	6.22	79.7	4.75	7.80	12.55	67	1.98	24.84	132
2007	5.83	6.35	81.4	7.16	7.80	14.96	192	1.89	28.22	362
2008	6.17	6.50	83.3	7.40	7.80	15.20	248	1.80	27.30	445
2009	4.60	6.52	83.6	5.51	7.80	13.31	197	1.71	22.76	336
2010	5.40	6.43	85.1	6.35	7.55	13.90	188	1.63	22.64	306
2011	6.15	6.62	87.6	7.02	7.55	14.57	335	1.55	22.61	520
2012	5.59	6.72	88.9	6.29	7.55	13.84	434	1.48	20.45	641
2013	5.04	6.78	89.7	5.62	7.55	13.17	591	1.41	18.53	832
2014	6.13	6.91	91.5	6.70	7.55	14.25	484	1.34	19.10	649
2015	9.46	9.46	92.5	10.23	10.23	20.47	606	1.28	26.12	773
2016	10.52	10.52	93.8	11.21	11.21	22.43	693	1.22	27.26	842
2017	10.48	10.48	95.3	11.01	11.01	22.01	711	1.16	25.48	823
2018	11.73	11.73	97.4	12.04	12.04	24.08	793	1.10	26.54	875
2019	12.16	12.16	99.3	12.24	12.24	24.48	807	1.05	25.71	847
2020	13.28	13.28	100.0	13.28	13.28	26.55	968	1.00	26.55	968
2021			100.0				851	0.95		810
2022			100.0				933	0.91		846
2023			100.0				976	0.86		843
2024			100.0				1013	0.82		833
2025			100.0				1045	0.78		819
2026			100.0				1043	0.75		778
2027			100.0				1157	0.71		822
2028			100.0				1197	0.68		810
2029			100.0				1239	0.64		799
2030			100.0				1202	0.61		738
2031			100.0				1164	0.58		681
2032			100.0				1083	0.56		603
2033			100.0				1042	0.53		552
2034			100.0				1002	0.51		506
2035			100.0				965	0.48		464
2036			100.0				928	0.46		425
2037			100.0				893	0.44		389
2038			100.0				856	0.42		356
2039			100.0				821	0.40		325
2040			100.0				787	0.38		297
2041			100.0				753	0.36		270
2042			100.0				720	0.34		246
2043			100.0				690	0.33		225
2044			100.0				661	0.31		205
2045			100.0				633	0.30		187
2046			100.0				606	0.28		171
2047			100.0				580	0.27		155
2048			100.0				555	0.26		142
2049			100.0				531	0.24		129
Total									685	23,840

Sources: [1] 1995 – 2012 Gray et al. 2012, 2012-2020 as reported by WGRF, SaskWheat, AWC, MCA and SWCDC; [2] StatsCan annual average CPI (2020=100);[3] Calculated from column A and B, using CPI ; [4] Value of genetic production increase; [5] Discount factor at a 5% annual interest rate $\left(\frac{1}{1+.05}\right)^{(t-2020)}$; [6]Discount factor applied to column F ; [7]Discount factor applied to column G.

To determine the benefit-cost ratio (B/C) for producers, Canadian consumers, foreign consumers, and taxpayers for levy-funded and public varietal R&D investments, we need to consider how each group contributes to levy-funded and public research, and how each group benefits from the varietal R&D investments.

On the investment or cost side, we assume taxpayers incur the cost of publicly funded varietal R&D investments[2]. The costs of levy-funded research, while deduced from producer payments, are actually partially shared with consumers. This effect is illustrated below.

Estimating the share of levy costs borne by consumers and producers

A 'check-off' or a levy drives a very small wedge ($1/t) between the price the buyer pays and the price the producer pays. This tends to drive up the buyer's or consumer's price and drive down the price the producer receives. Thus. the buyer pays some of the cost of a levy through higher prices and the producer pays some of the cost through lower price received. The proportion of the levy borne by the buyer and the seller depends on the slopes of the relative elasticities of supply and demand.

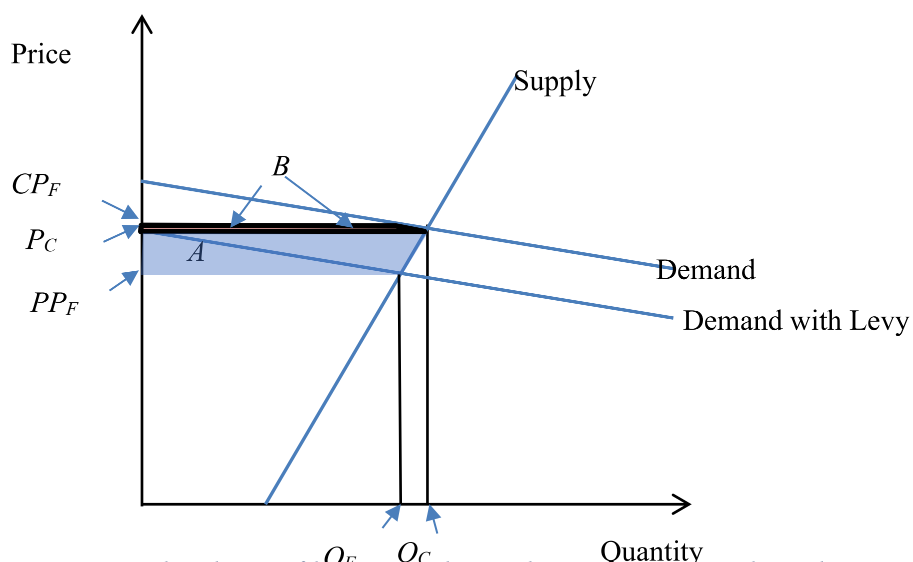

Figure A1: The share of levy costs borne by consumers and producers

The sharing of the cost of the levy can be calculated if we know the relative supply and demand elasticities. The elasticity of demand, $\eta = \left(\frac{\%\ Change\ in\ Qd}{\%\ in\ P}\right) = \frac{\partial Q}{\partial P}\frac{P}{Q}$, is the percentage change in the quantity demanded for a one percent increase in price, and elasticity of supply $\varepsilon = Q_{Ft}\left(\frac{\%\ Change\ in\ Qd}{\%\ in\ P}\right) = \frac{\partial Q}{\partial P}\frac{P}{Q}$, which is percentage change in supply for a 1% change in price.

Similar to Scott et al., (2005) and Gray et al. (2012), we use Iowa State FAPRI's estimates of demand elasticity equal to -10 and supply elasticity equal to 0.4 for Canadian wheat.

With linear supply and demand functions it is relatively straight forward to calculate the impact of a levy

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[2] While producers and consumer are also often taxpayers, we consider the taxpayers separately from wheat consumers and producers.

on supply on the equilibrium prices, and the proportion of the levy cost borne by the producers and consumers. If we let P_c represent the buyers' (consumers) price, then the price received by the producer is the buyers' price minus the levy or $P_p = P_c - v$, where v the per unit levy.
Given this relationship we can restate the supply and demand relationships as a function of the buyers' price and the per unit levy rate v.

$$Q_D = A - BP_c$$
$$Q_S = a + b(P_c - v)$$

At a market equilibrium, the quantity of Canadian wheat supplied Q_S is equal to the quantity demanded, Q_D or:

$$A + b(P_c - v) = A - BP_c$$

This allows us to solve for price as a function of v.

$$(b + B)P_c = A - a + bv; \text{ so,}$$

$$P_c = \frac{A - a + bv}{(b + B)}, or\ P_c = \frac{A - a}{(b + B)} + \left(\frac{b}{b + B}\right)v.$$

Taking a derivative of the P_c with respect to v is equal to $\frac{\partial P_c}{\partial v} = \frac{b}{b+B}$.

We can convert this relationship to elasticities because we know:
$\eta = -B\frac{P}{Q}$; therefore $B = -\eta\frac{Q}{P}$, and $b = \varepsilon\frac{Q}{P}$; So:

$$\frac{\partial P_c}{\partial v} = \frac{\varepsilon\frac{Q}{P}}{\left(\varepsilon\frac{Q}{P} - \eta\frac{Q}{P}\right)}, or\ \frac{\partial P_c}{\partial v} = \frac{\varepsilon}{(\varepsilon - \eta)}$$

Therefore, the increase in the consumer price is $\Delta P_c = \frac{\varepsilon}{(\varepsilon-\eta)}\Delta v$, and the corresponding decrease in the producer price is:

$$\Delta P_P = \left[\frac{\varepsilon}{(\varepsilon - \eta)} - 1\right]\Delta v$$

Given FAPRI's estimate of the demand elasticity (η) =-10 and the supply elasticity (ε) $= .4$, The proportion of the $1 levy borne by the consumers (or more specifically everyone beyond the farm gate) is reflected in a higher price $\frac{\varepsilon}{(\varepsilon - \eta)} = \frac{.4}{10.4} = .0384$, which is 3.8 cents per dollar of levy paid.

The producers' share is reflected through a lower price of $\frac{\varepsilon}{(\varepsilon - \eta)} - 1 = -$ 0.962, or 96.2 cents of every dollar paid.

Or, for every $1 increase in levy the buyer price increases by $0.0384 (3.8 cents) and the producer price is reduced by $1- $0.0384 = $.966 or 96.6 cents. This means that 3.84 cents of cost of a $1 levy is borne by consumers and 96.6 cents is borne by the producer. The consumer's cost of the levy is further split with 15% of the 3.84 cents (.13 cents) paid by Canadian buyers and 85% of the 3.84 cents (3.26 cents) paid by the foreign wheat buyers. These proportions are applied to the cost of the levy investments as reported in Table 3.

The government portion of the varietal R&D investment is a cost to taxpayers.

Estimating the Sharing of Benefits from the increase in production

Consumer and producers both benefit from the output of varietal R&D investment. Producers benefit from increased production and consumers benefit from reduced prices. As shown in Figure A2, increases in production have an impact on prices, which have an impact on the benefits received by producers and consumers. Producers gain economically from additional production shown as area *E*, but give up area *A* to consumers (or buyers) of their grain because prices are lower. Consumers also receive a small additional area B from the resulting increase in production.

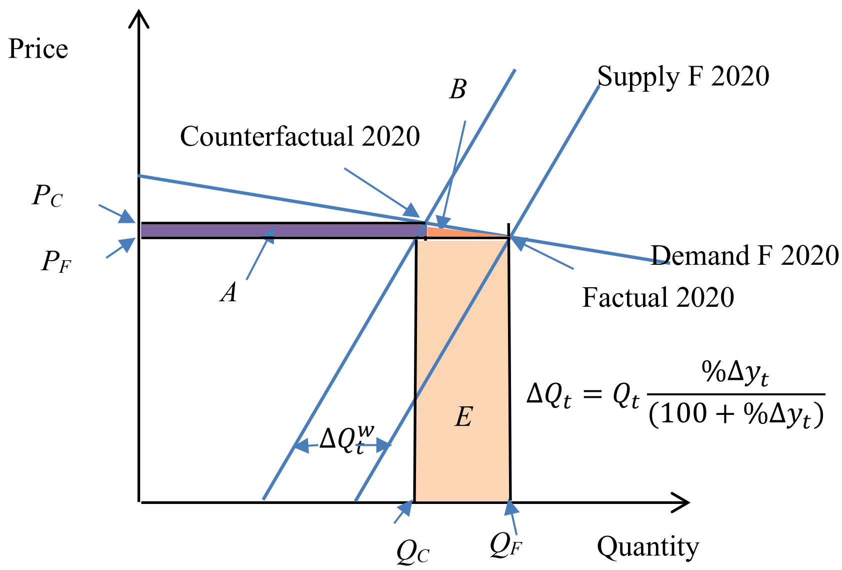

Figure A2: The sharing of benefits from an increase in production

With linear supply and demand functions it is relatively straight forward to calculate the impact of autonomous increase supply on the equilibrium prices.

If we assume the production in any given year is proportion to the weighted average index in that year ie. $Q_t \approx Q_t\, Y_t,$ then the counterfactual production in *t*, (ie. The production that would have occurred if the weighted average index was equal to the 2004 yield index) quantity production in any given year, multiplied by counterfactual 2004 yield index.
$Q_t^c = Q_t Y^c$

As described on page A3, this rightward shift of the supply in any given year due to genetic improvement is

$$\Delta Q_t = Q_t \frac{Y_t - Y^c}{(100 + Y_t)} = Q_t \frac{\%\Delta Y_t}{(100 + \%\Delta Y_t)}.$$

To keep the algebra a little easier to show, if we define the proportion reduction in the current yield as $\Delta k,$ then

$$\Delta k = \frac{\%\Delta Y_t}{(100+\%\Delta Y_t)} = \frac{\Delta Q_t}{Q_t}.$$

Beginning with linear supply and demand functions we can show the effect of a proportion increase in supply on prices.

$$Q_D = A - BP$$
$$Q_S = a + kQ + bP,$$

At a market equilibrium the Quantity supplied is equal to the quantity demanded or:

$$a + Qk + bP = A - BP$$

This allows us to solve for price and function of k the increase in supply.

$$(b + B)P = A - a - k$$
$$P = \frac{A - a - kQ}{(b + B)}$$

Taking a derivative, we can show the reduction in price *P* in inversely related sum of slopes of the supply and demand functions or:

$$\frac{dP}{dk} = \frac{-Q}{b + B}$$

We can convert this relationship to elasticities because we know:
$\eta = -B\frac{P}{Q}$; therefore $B = -\eta\frac{Q}{P}$, and $b = \varepsilon\frac{Q}{P}$; So

$$\frac{dP}{dk} = \frac{-Q}{\left(\varepsilon\frac{Q}{P} - \eta\frac{Q}{P}\right)},$$

$$\frac{dP}{dk} = \frac{-1}{(\varepsilon - \eta)}P \quad or \quad \frac{dP}{P} = \frac{-1}{(\varepsilon - \eta)}dk \quad or \quad \frac{\Delta P}{P} = \frac{-1}{(\varepsilon - \eta)}\frac{\Delta Q_t}{Q_t} \quad or \quad \frac{\%\Delta P}{\%\Delta Q_t} = \frac{-1}{(\varepsilon - \eta)}.$$

Using the FAPRI's demand elasticity of -10.0 and the supply elasticity of 0.4 we can calculate the price effect of a 1% shift in the supply curve.

$$\frac{\frac{\Delta P_t}{P_t}}{\frac{\Delta Q_t}{Q_t}} = \frac{-1}{(\varepsilon - \eta)} = \frac{-1}{(.4 + 10)} = -.0962$$

Noting that $\frac{\%\Delta Y_t}{(100+\%\Delta Y_t)} = \frac{\Delta Q_t}{Q_t}$, $\Delta P_t = -.0962\, P_t\left(\frac{\%\Delta Y_t}{(100+\%\Delta Y_t)}\right)$.

So, a yield index increase of 10% prices would decrease by .962%, benefiting both domestic and foreign consumers.

This price decrease also reduces the net benefits to producers. To calculate the total value of benefit producers are transferring to consumers this price drop is multiplied by the counterfactual production, or:

$$Transfer = -.0962\, P_t\left(\frac{\%\Delta Y_t}{(100 + \%\Delta Y_t)}\right) \times Q_t \times \left(1 - \frac{\%\Delta Y_t}{(100 + \%\Delta Y_t)}\right)$$

The net benefits to producers (increase in producer surplus, ΔPS) are equal to the gross annual research benefit minus this transfer of benefits to consumers.

The increase in the producer surplus (PS_t) is therefore:

Producers' benefit:

$$PS_t = P_t Q_t \frac{\%\Delta Y_t}{(100+\%\Delta Y_t)} - .0962\, P_t \left(\frac{\%\Delta Y_t}{(100+\%\Delta Y_t)}\right) \times Q_t \times \left(1 - \frac{\%\Delta Y_t}{(100+\%\Delta Y_t)}\right),$$

$$PS_t = P_t Q_t \frac{\%\Delta Y_t}{(100 + \%\Delta Y_t)} \left(1 - .0962 \left[1 - \frac{\%\Delta Y_t}{(100 + \%\Delta Y_t)}\right]\right)$$

Assuming the term in the square brackets is close to one, the increase in producer surplus can be rounded down to:

$$PS_t \approx .904\, P_t Q_t \frac{\%\Delta Y_t}{(100+\%\Delta Y_t)} = .904\, GB_t.$$

This conservative approximation was applied to calculate the producer benefits, in Table 3 and 4.

The total benefits consumers receive from increased production is illustrated in the Figure 2, as area A that is transferred from producers through lower prices, plus the smaller area B, which reflects the additional benefit of consuming more at the lower price.

We allocate the residual GB_t to the consumer surplus. This is also an under-estimate because consumers receive the benefits from lower prices on their consumption in year *t,* not only on their counterfactual level of consumption.

The total benefit to consumers is equal to:

$$CS_t = .0962 \frac{\%\Delta Y_t}{(100 + \%\Delta Y_t)} P_t\, Q_t - .5(.0962) \left(\frac{\%\Delta Y_t}{(100 + \%\Delta Y_t)}\right)^2 P_t\, Q_t.$$

Given the relatively small percentage yield growth, the last squared term is very small. We therefore approximate the annual increase in consumer surplus resulting for the varietal R&D investments in each year t as:

$$CS_t \approx .0962 \frac{\%\Delta Y_t}{(100 + \%\Delta Y_t)} P_t\, Q_t$$

Note that with this approximation the gross annual research benefit is allocated between producers and consumers, with the small area B not being accounting for.

Finally, we assume this consumer benefit is shared between Canadian and foreign consumers in proportion to relative market shares of 15% and 85% respectively.

Benefit Cost Ratios

As it is written, the benefit-cost ratio (B/C) is the ratio of Present Value of the Benefits to the Present Value of costs. As present values, these ratios consider the time value of money. B/C ratios greater than 1 reflect good choices. Benefit ratios of 3 or 4 to one are excellent investments. B/C ratios greater than 30 are investments with extremely high returns.

The overall benefit cost ratio:

$$Total\ Benefit\ Cost\ Ratio = \frac{Present\ Value\ of\ Total\ Benefits}{Present\ Value\ of\ Total\ Cost}$$

Reflects the world or global return to these investments.

The B/C ratios for producers, consumers, and taxpayers, represent the ratio of their benefits to their costs.

$$Producer\ Benefit\ Cost\ Ratio = \frac{PV\ of\ Producer\ Benefits}{PV\ of\ Producer\ Cost}$$

The Internal Rate of Return

As described in the report, and in the finance literature, the internal rate of return for a B/C study is the discount rate where the B/C ratio is equal to one. The internal rate of return of 33% indicates that an investor could borrow money at a 33% interest rate and still break even on the investment. Any internal rate of return about the market (real) rate of interest would be considered viable investment. An investment with an internal rate of return of 33 % will double its value every 30 months.