AN EXAMINATION OF FACTORS INFLUENCING PRODUCER ADOPTION OF HT CANOLA

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An Examination of Factors Influencing Producer Adoption of HT Canola

A Thesis
Submitted to the College of Graduate Studies and Research
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in the Department of Agricultural Economics
University of Saskatchewan
Saskatoon

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ABSTRACT

Keyowski, Lynette R. 2004. M.Sc. University of Saskatchewan, Saskatoon, August 2004. An Examination of Factors Influencing the Adoption of HT Canola. Supervisor: Dr. Murray E. Fulton

This thesis develops a conceptual framework to determine the probability of adopting HT canola when producers are assumed heterogeneous. The model is based on the framework developed by Fulton and Keyowski (1999), but is modified from a deterministic model to a probabilistic model. The study also considers the gross returns from adopting HT canola. Canola production in Manitoba, Canada is chosen as the region of analysis for the empirical component of the study.

In 2002, 74 per cent of total canola acres in Manitoba were devoted to HT canola production. Factors such as soil type, producer risk profile, experience, productivity, and management ability are considered as potential determining factors which distinguish adopters of HT technology from non-adopters.

Based on an initial assessment of Manitoba canola data, which shows the incomplete adoption of HT technology in Manitoba, a model is developed which considers adoption of a new technology as a function of the characteristics of the adopters. The conceptual model is tested empirically in two-stages. The first stage employs Ordinary Least Squares analysis to estimate the expected yield of different canola varieties to determine whether producers realize a benefit from the adoption of HT varieties. A logit analysis is conducted in the second stage, and considers different attributes of producers – such as risk aversion, management ability, productivity and expected yields – to determine the probability of producers adopting HT technology.

The results show two primary findings. First, certain HT varieties can be shown to give producers higher returns. Second, differentiating characteristics of producers are key in determining the likely adoption of HT canola.

ACKNOWLEDGEMENTS

The author wishes to thank the following in the completion of this thesis:

My supervisor, Dr. Murray Fulton, for his knowledge and guidance, but mostly for his untiring patience, understanding and support;

The members of my advisory committee, Drs. Richard Gray and James Nolan for their guidance and support;

The Saskatchewan Canola Development Commission for the financial contribution made toward the completion of this thesis;

The Strategic Research Program for financial contribution made toward the completion of this thesis;

Manitoba Crop Insurance Corporation for making available the data used in the empirical analysis;

My parents, Glorian and Theresa, for their unconditional encouragement, love and support.

For Dakota
My reason –
I love you.
Mom

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1 INTRODUCTION

Technological change has been a critical element of agriculture over the last 100 years. Innovation in the industry has been the basis for increasing agricultural productivity and promoting agricultural development worldwide (Schulz, 1964; Alston, Norton and Pardey, 1995). The agriculture industry has benefited from innovation in many aspects of production, including mechanical innovation, biological innovation, chemical innovation, agronomic innovation and informational innovation. Any new method, custom or device created to perform a new task can be defined as an innovation (Sunding and Zilberman, 2001). Stoneman (2002) defines innovations that are created to perform new task, or that are advances in techniques used in production, as process innovations. Conversely, product innovations are defined by technological advances in the nature and type of products produced.

Of course, innovation is only successful if the innovative technology is adopted. If and when a new technology is adopted depends on a wide range of factors faced by individual producers, including geography, time, risk preferences and investment requirements. There is a vast literature surrounding adoption and diffusion of innovations, including Mansfield (1963); Stoneman and Ireland (1983); McDonald and Siegel (1986); Olmstead and Rhode (1993); Rogers (1995); and McWilliams and Zilberman (1996).[1]

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[1] These works will be discussed in more detail in Chapter 3.

In the late twentieth century and early twenty-first century, some of the most prevalent products of technological change have been the result of biotechnology – in particular, genetic modification of plants. Examples of biotechnology that have become important in the western hemisphere include the Roundup Ready© and Bt technologies.

As this thesis attempts to explain the economic impacts of an innovation, herbicide tolerant canola, generated from a scientific process, specifically biotechnology, clarification of terms needs to be made. Science, as defined by Merriam-Webster (2004) is, "…the state of knowing: knowledge as distinguished from ignorance or misunderstanding." To scientists, therefore, the applicable definition of technology is, "…the practical application of knowledge, especially in a particular area." Hence, biotechnology – the practical application of knowledge "…[applied to] genetic engineering and recombinant DNA technology." For the sake of this thesis, in its explanation of the economic impacts of an innovation based on biotechnology, technology is defined as, "…a manner of accomplishing a task, especially using technical processes, methods or knowledge." In the case of herbicide tolerance, the technology is used to control weeds.

The advent of biotechnology as an impetus for technological innovation has not only changed the mechanism by which new crops are developed, but has also diminished the amount of time it takes for new technologies to become commercially available. With the advent of genetic modification (a biotechnological process) in the canola industry, for example, the average time to breed and commercially register a new variety diminished from approximately 15 years to between 6 and 10 years, depending on the breeding method used. In addition, private investment into research and development of new varieties using biotechnological processes has increased the number of varieties available for commercial trade. With the introduction of biotechnology methods, the number of varieties released each year increased steadily from less than one during the years 1985-89 to a peak of 32 registered varieties in 1996 (Phillips, 2001).

Agricultural producers, in general, have been very receptive of biotechnology, and have readily adopted many of the resulting technologies. On a global scale, the area of crops derived from biotechnology has increased from 4.3 million acres at its inception in 1996 to 167 million acres in 2003. The United States is, by far, the leading producer of genetically modified (GM) crops, with 63 per cent of this area. Argentina and Canada follow with 21 and six per cent, respectively, of the total global area in production of GM crops in 2003 (James, 2003).

As Table 1.1 shows, the largest proportion of GM commodities grown in the world are either tolerant to certain herbicides, have been made resistant to particular insects, or display a combination of both characteristics. Of the reasons producers have so readily adopted GM technologies, the cost reduction and yield enhancements that result from using these products appear to be at the top of the list. Marra, Pardey and Alston (2002) show that research on farm-level impacts in the United States confirms yield enhancements and reduced pesticide use in transgenic crops when compared to conventional varieties, with the expectation that these results would be paralleled in other countries.

Table 1.1 - Global Area of Transgenic Crops by Trait, 2000-02 (million hectares)

Trait	2000	% Total Transgenic Acres	2001	% Total Transgenic Acres	2002	% Total Transgenic Acres
Herbicide Tolerance	28.1	71	40.6	77	44.2	75
Insect Resistance	8.9	22	7.8	15	10.1	17
Bt/Herbicide Tolerance	2.9	7	4.2	8	4.4	8
Virus Resistance/Other	<0.1	<1	<0.1	<1	<0.1	<1

Source: Adapted from James (2000 &2002).

The traits specified in Table 1.1 are predominantly agronomic traits (i.e., directly affect production of the commodity). Biotechnology has also been used to change other criteria such as crop yield or crop quality. In the case of canola, for example, biotechnology has been responsible for developing traits with respect to oil composition and meal quality (Khachatourians *et al.,* 2001).

In Canada, the predominant biotech commodity that has been adopted is herbicide tolerant (HT) canola. While a large portion of the industry has adopted HT canola, there are a significant proportion of producers who have not. Table 1.2 depicts Canadian canola acres from 1996 to 2002. Over the first four years of this period, Canadian acres planted to canola steadily increased, from 8.8 million acres in 1996 to 13.75 million acres in 1999. Over the same period, 1996 to 1999, the proportion of those acres seeded to HT canola also steadily increased, from 4 per cent of total canola acres in 1996 to 62 per cent of total canola production in 1999.

Table 1.2 - Acres of Herbicide Tolerant Canola in Canada ('000s acres).

	1996	1997	1998	1999	2000	2001	2002
Total Canola	8,843	12,040	13,535	13,750	12,192	9,353	8,059
Herbicide Tolerant	350	4,000	6,000	8,500	7,000	5,857	5, 930
Per Cent of Total	**4**	**33**	**44**	**62**	**57**	**62**	**74**

Source: Fulton and Keyowski (1999), James (2000, 2001 & 2002), Canola Council of Canada (2003) and author's calculations.

Since 1999, total area in Canada planted to canola has steadily declined, to a low of just over 7 million acres in 2002. While the total number of acres seeded to canola has diminished, more of the producers who continue to seed canola are choosing to seed HT varieties, with 62 per cent of canola acres in 2001 and 74 per cent in 2002 devoted to growing HT canola.

The focus of this thesis is on producer adoption of canola varieties which exhibit a specific trait – herbicide tolerance (HT). While some varieties of HT canola are products of biotechnology, not all HT varieties are a result of modern genetic modification practices.

Alan McHughen (2000) notes that the term 'biotechnology', in a general sense, encompasses, "… any application of technology to living systems." While McHughen acknowledges that the term 'biotechnology' more commonly refers to 'modern' technologies such as genetic engineering, it is not to be confused as a synonym with genetic modification, which he defines in the following manner:

> "**Genetic modification** (GM), also known as **genetic engineering** or **rDNA technology**, is actually a collection of many technologies. These begin, perhaps, with the molecular identification and analysis of genes and DNA. They include extraction and isolation, then 'cloning' or multiplying fragments of DNA or genes. They include gene-splicing, cutting pieces of DNA, and connecting together fragments from different sources. They also include shifting the DNA from test tube to Petri dish, or from bacteria to other bacteria. They may involve subtle or substantial directed alteration of the DNA along the way. They could also include transferring or inserting the DNA into the cell of a higher plant or animal, then recovering a complete new organism. Only this last stage is what most of us consider when defining 'genetic engineering'…
>
> The application of GM techniques results in a **genetically modified organism** (GMO), also known as a **transgenic** or **genetically transformed** organism." (McHughen, 2000)

One biotechnological process which is not described by the above definition, but by which the same type of results can be obtained, is mutagenesis. In this form of manipulation, the genetic material of an organism is subjected to an agent which causes mutation to alter its genetic makeup, in anticipation of obtaining the trait of interest. The mutated plant material is then selected for the desired trait.

In the case of HT canola, varieties that are resistant to glyphosate – the active ingredient in the herbicide Roundup® – are selected based on rDNA techniques, and would therefore be considered genetically modified, herbicide tolerant by the above definition. Canola varieties that are part of the Clearfield® system – those which are resistant to imazethypyr, the active ingredient in the commercial chemicals Pursuit® and Odyssey® – are selected based on mutagenesis techniques, and would thus be classified as non-genetically modified, herbicide tolerant varieties by McHughen's definition.

Despite the relative acceptance of the herbicide tolerant technology (recall that 75 per cent of Canadian canola acres in 2002 were HT), there remains a significant portion of the industry that chooses to produce traditionally bred varieties of canola. A cursory glance at the canola sector may potentially provide an explanation for the incomplete diffusion of HT canola.

A host of issues has surrounded the canola industry with the advent of biotechnology. Issues such as cross-pollination with traditional canola; the inability for producers to save seed, depending on the variety grown; continued adoption of complimentary technologies, such as zero-tillage; and the continuing skepticism of importing nations about the safety of GM products are all concerns that have affected how the producer perceives canola as a product. Where consumer demands are reflected through price signals, simply the threat of a decreased price for HT canola (or, alternatively, the potential for a price premium for non-HT canola) may be enough to keep producers from using HT technology.

Another explanation for the partial adoption of HT canola is the heterogeneous nature of producers. Producers differ in terms of geographic location, agronomic factors, management ability and behavior under risk (Fulton and Keyowski, 1999). The returns from adoption of HT canola can be quite easily measured if all producers are assumed to be homogeneous in both their adoption and production patterns of the technology. Relaxing this assumption of producer uniformity and allowing for producer differentiation in production of canola makes measurement of producer benefits much more difficult. Works by David (1975) and others have considered the heterogeneous nature of producers in adopting new technologies. To date, however, there has not been a widespread attempt to model the adoption of HT technology, or measure benefits derived from it under the assumption that producers are heterogeneous.

The motivation for this thesis stems from the need to develop an appropriate conceptual model with which to: (1) determine the probability of HT adoption; and (2) measure the benefits to producers from producing HT canola. Specifically, this thesis aims to: (a) develop a conceptual framework with which to measure the returns to producers from the adoption of HT canola, under the assumption that producers are heterogeneous in their production of the commodity; (b) empirically estimate the expected yields of HT and non-HT canola to test the hypothesis that the HT technology is yield enhancing; (c) determine the probability of a producer adopting HT canola, given specific production attributes; and (d) measure the benefit to producers from HT production, given the probability of adoption.

The remainder of this thesis is arranged as follows. An assessment of canola production in Manitoba, Canada is presented in Chapter 2. Manitoba is chosen for analysis in this study because it is agronomically and climatically well-suited for the production of canola; it is the third largest canola producing province in Canada. In addition, the provincial crop insurance program was able to provide the data essential for the analysis contained in this thesis. The purpose of Chapter 2 is to utilize producer reported data from the province to highlight the incomplete adoption of HT canola. Initial analysis of the producer reported data will provide evidence that adopters and non-adopters can be distinguished by certain characteristics.

With the onset of biotechnology, research and development (R&D) of agricultural innovations has shifted from the public to the private sector. This shift in the R&D effort has changed how the resulting innovations are supplied to the production sector. The literature on the benefits to producers from the adoption of new agricultural innovations will be reviewed in Chapter 3. This literature can be divided into two categories. The first looks at the returns to innovations that are developed through public R&D, while the second approach examines returns to innovations that are developed through private R&D and distributed through the market and contractual arrangements established by the private sector firms. The literature on the factors that affect adoption will also be examined in Chapter 3 to develop a clearer understanding of why producers adopt new technologies.

A conceptual framework is developed in Chapter 4 that looks at the adoption of HT canola specifically as a function of the differing characteristics of producers. The model shows that even as technologies become better and cheaper over time, there may only be a subset of producers who will benefit from adoption.

Application of the conceptual model to the canola sector in Manitoba is presented in Chapter 5. The model is tested empirically using a two-stage regression model. In the first stage, individual characteristics such as soil type, year and variety grown are regressed on yield. From this analysis, expected yields of HT and non-HT canola are obtained to determine whether HT canola has a yield advantage over non-HT canola. These expected yields are then used to estimate the gross returns to different farmers from the adoption of different varieties of canola. The second stage of analysis uses the expected yields from the first stage, as well as proxy variables for risk, management ability and experience, to determine the probability of a producer adopting HT canola. The second stage of the analysis is conducted as a limited dependent variable model, and is estimated using a logit regression.

Chapter 6 summarizes the findings of the empirical analysis. Limitations of the study will be discussed, and recommendations for further research will be suggested.

2 CANOLA PRODUCTION IN MANITOBA, CANADA

Canola has been deemed Canada's 'Cinderella' crop. The result of an aggressive Canadian rapeseed breeding program in the 1970s, the term 'canola' – registered as a trademark in 1978 – reflected a differentiated product from traditional rapeseed. The 'new' rapeseed, canola, had improved product qualities, boasting low erucic acid oil and low glucosinolate meal – attributes that traditional rapeseed lacked – which made it ideal for both human food and animal feed consumption (Khachatourians *et al.*, 2001). These attributes increased demand for the product on the global market, and Canadian producers responded – partially to offset the economic burden from overproduction of cereals – by becoming the world's largest exporter of canola.

In 2003, Canada was the third largest producer of canola/rapeseed, with 11 per cent of the world's production, next only to China (33 per cent) and the European Union (29 per cent) (Agriculture and Agrifood Canada, 2003). The primary growing regions for canola in Canada are the three Prairie Provinces – Alberta (including the Peace River region, which partially extends into British Columbia), Saskatchewan and Manitoba – with some smaller production in Ontario and Quebec.

To study the adoption of herbicide tolerant canola, this thesis examines grain and oilseed producers in the province of Manitoba, Canada. Manitoba's climate and soil conditions allow producers to have a very diverse portfolio of commodities under production. While wheat and barley still constitute the largest part of grain production (43 per cent of the province's harvested area in 2000), the fertile

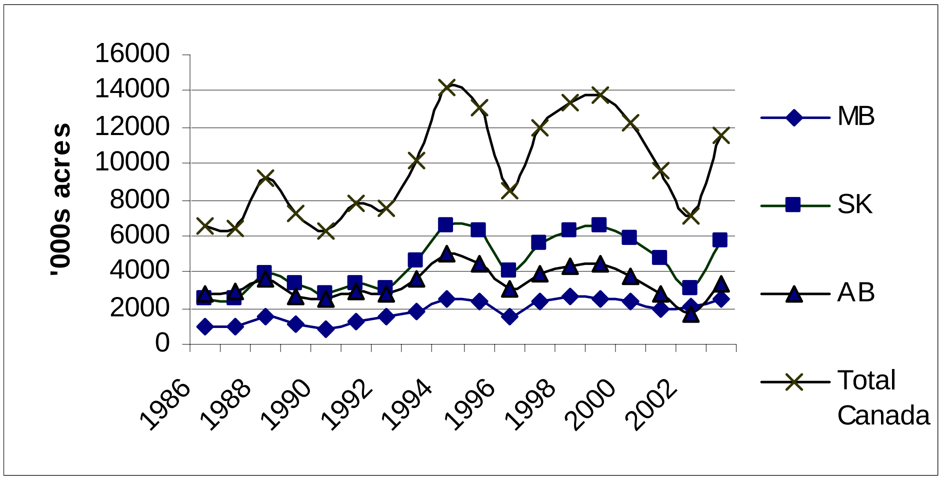


Figure 2.1 - Canola Production - AB, SK, MB and Total Canada, 1986 - 2003

southern part of the province also allows production of less traditional Canadian prairie commodities such as sunflower (approximately 85 per cent of national production), buckwheat, grain corn, potatoes and vegetables [Manitoba Agriculture and Food (2002)].

On average, Manitoba produces approximately 20 per cent of the Canadian canola crop. Total canola production in Manitoba has averaged 1.8 million acres between 1986 and 2003 – it is the third largest canola producing province, next to Saskatchewan (4.5 million acres) and Alberta (3.5 million acres) (Figure 2.1).

Manitoba producers began adopting herbicide tolerant canola in 1995, the first year the product became commercially available. Table 2.1 reports acres of canola reported to Manitoba crop insurance from 1995 to 2000. The data reported to crop insurance represents an average of 77.5 per cent of the total acres sown to canola over this period. Table 2.1 also reiterates Canada's canola production, and shows that adoption of HT canola in Manitoba very closely mirrors the adoption rate at the national level. It is evident that while a portion of producers have found it viable to adopt the technology, not all producers have done so. This leads to the question of what distinguishes adopters from non-adopters of this technology.

Table 2.1 - Adoption of HT Canola, Manitoba and Canada 1995-2000.

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Manitoba									
Total Canola Acres	1,652	1,158	1,909	2,198	1,916	1,773	1,930	2,150	2,490
HT Acres	65	193	777	1,301	1,320	1,320	n.a.	n.a.	n.a.
Per cent HT of total	**4**	**17**	**41**	**59**	**69**	**65**	n.a.	n.a.	n.a.
Canada									
Total Canola Acres	-	8,843	12,040	13,535	13,750	12,192	9,601	7,060	11,587
HT Acres	-	350	4,000	6,000	8,500	7,000	5,857	5,930	n.a.
Per cent HT of total	**-**	**4**	**33**	**44**	**62**	**57**	**61**	**84**	n.a.

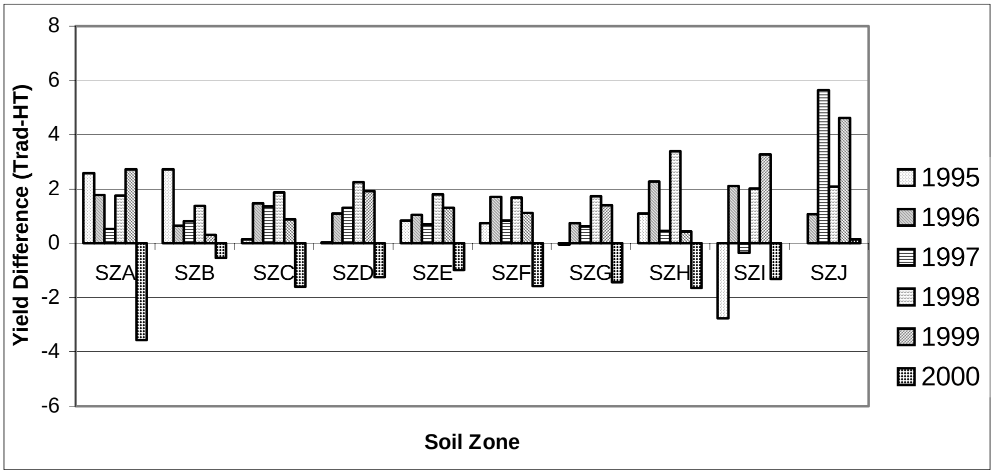
Source: MCIC database; Author's Calculations; Fulton and Keyowski (1999); Canola Council of Canada (2003); James (2000, 2001, 2002).

There are many factors that affect the production decisions of producers, including soil type, past agronomic management, past weather conditions and differing field 'states' or conditions, that producers have little choice over. Other production factors such as the type of crop rotation to use, which commodities to plant, and where and how to market the product are factors that require producers to make a decision. The choice of adopting new technologies such as herbicide tolerance or reduced tillage systems are just two examples of the many decisions that producers have to make. Each producer will make these decisions based on an equally diverse set of criteria, such as his individual objectives, management abilities or planning horizons. A common observation is that no two producers will make exactly the same decision at the same time regarding any or all of these issues. Perhaps a good explanation is the degree of diversity that is inherent in modern day agriculture. There are numerous traits by which one person can be defined as being different from another. Producers can differ from one another according to such things as age, level of education, size of farm, the tillage system employed, geographic location, skill, management ability and attitude towards risk. Each of these factors plays a role in the decisions made by producers.

The purpose of this chapter is to examine one decision made by farmers – the adoption of HT canola – by exploring a sample of Manitoba producers. Specifically, the chapter will examine data from the Manitoba Crop Insurance database in an effort to assess what distinguishes adopters of the technology from non-adopters.

One easily determined factor that distinguishes producers is the type of soil on which they grow their crops. There are ten soil types defined by Manitoba Crop Insurance Corporation within the province, classified from *A* – the most productive – through *J* – the least productive. Productive classification is determined by historical yields as well as factors such as climatic and certain soil variables. Each land location in the province is rated according to this classification. It is important to note that while the classes are determined by their productive capability, they are not constant throughout the province. Each classification is specific to the risk area – an area that has common production risk with respect to soil and/or climatic similarities - it is in. For example, a *C* soil in Risk Area 9 may not have the same productivity as a *C* soil in Risk Area 12.

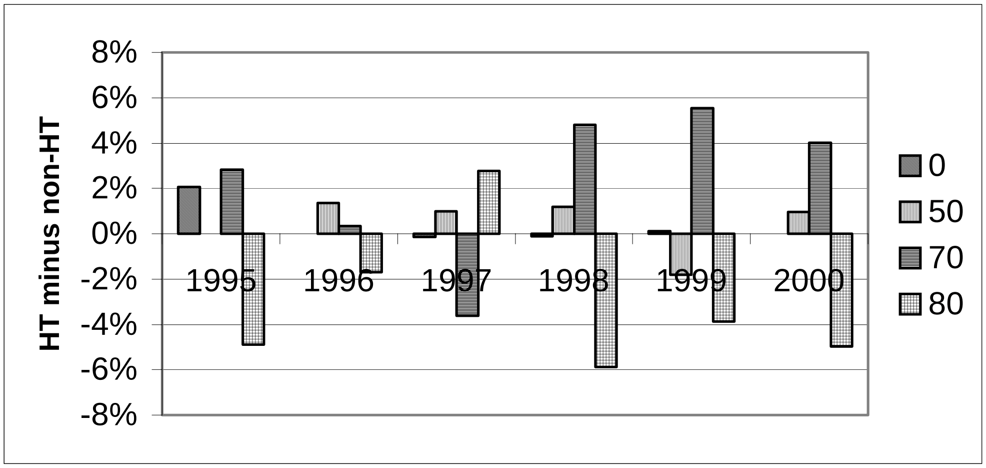
The difference in average yields between HT and non-HT canola according to soil type is shown in Figure 2.2. Positive values on the graph indicate that the average yields for non-HT canola are higher than those for HT. Several observations can be made from the figure. First, traditional canola has, on average, yielded higher than HT canola in all soil zones from 1995 to 1999, with the exception of the *I* soil in 1995. In 2000, however, HT canola out-yielded non-HT in all soil zones except the *J* soil. The differences (whether positive or negative) tend to be smaller in the central soil types (*C to G*) than at either end of the soil productivity spectrum. Non-HT canola seems to have a larger advantage in the less productive soils (*I* and *J*), and HT canola seems to have a greater advantage in the most productive soil (*A).*



Note: Positive values indicate a yield advantage for non-HT canola.

Figure 2.2 - Average yield difference, Traditional less HT, Manitoba Soil Zones A - J, 1995-2000.

Producers also differ in their attitude towards risk. Producers who insure at a higher level are assumed to be more risk averse than those who insure at lower percentages. Producers who choose to produce HT canola appear to be less risk averse than are those who seed traditional canola. Figure 2.3 depicts the percentage difference between the number of producers who seed HT canola less the number that seed non-HT canola at each insurance coverage level. Positive numbers indicate a higher percentage of producers that insure HT canola at each coverage level than non-HT canola. From Figure 2.3, producers who insure at the 70 per cent level appear more likely to grow HT canola – the one exception to this pattern is 1997, when a higher percentage of non-HT producers insured at this level. Producers who insure at the 80 per cent level are more likely to seed non-HT canola (again, with the exception of 1997). This data is consistent with the view that HT canola is a risk management tool; it is also consistent with HT canola growers being somewhat less risk averse.

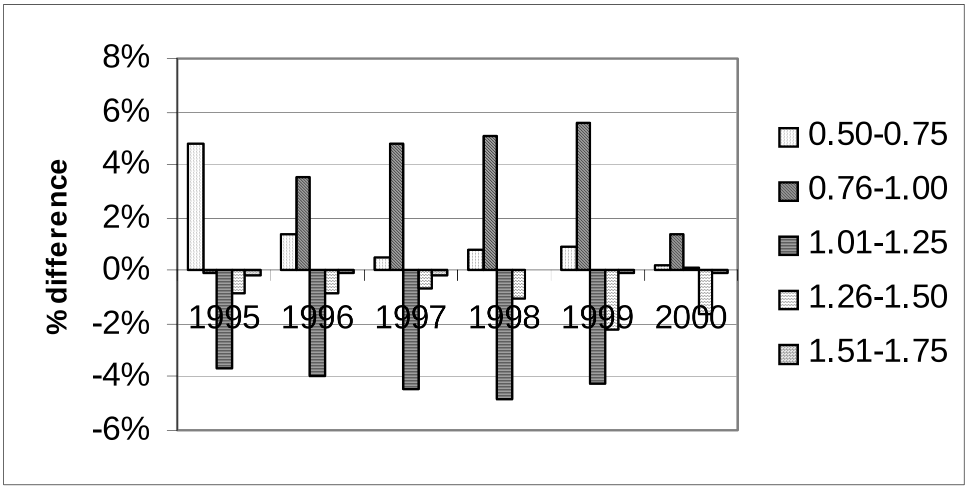


Note: Positive values indicate a higher percentage of HT producers at specified coverage level.

Figure 2.3 – Difference in percentage of producers at varying crop insurance coverage levels as indication of risk management patterns between HT adopters and non-adopters, Manitoba, 1995-2000.

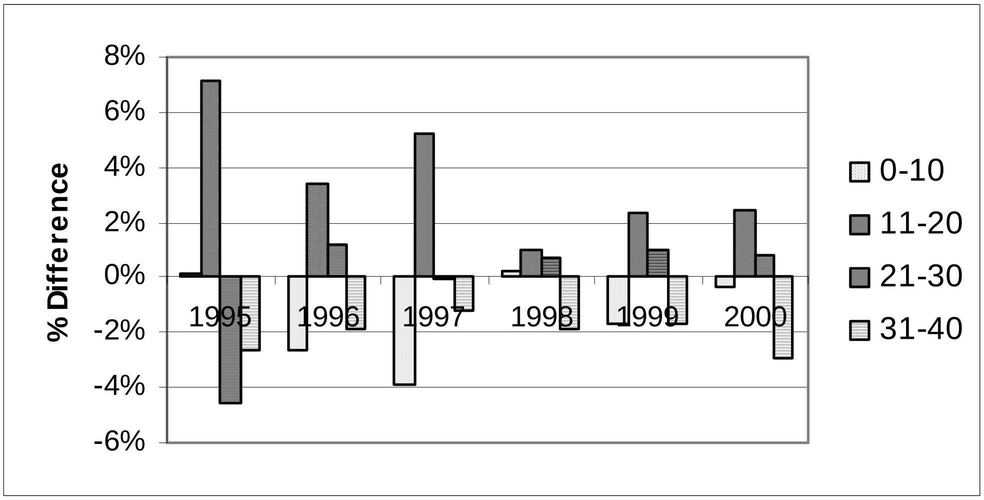
The way producers manage their operations may also have an effect on their choice of technology adoption. One measurement of producers' management ability is the individual productivity index (IPI). The IPI is a crop-specific ten year weighted average of a producer's yield, measured against the average yield for the area. Therefore, these indices are comparable across all producers as a proxy for management. The canola productivity index (CPI) is the calculated index for an individual relative specifically to canola. Producers of non-HT canola have consistently displayed a higher canola productivity index (CPI) in all six years of data available for comparison. The percentage difference of producers seeding either type of canola at each index level is shown in Figure 2.4. Positive values indicate the productivity level where there is a higher percentage of HT producers. At the lower productivity levels – e.g., at the 50 to 75 per cent and the 76 to 100 per cent levels – a greater percentage of producers grow HT canola. In the higher productivity categories – e.g., the 101 to 125 per cent and the 126 to 150 per cent levels – a higher percentage of producers grow non-HT canola.

Figure 2.5 shows the difference in percentage of HT and non-HT canola producers enrolled in crop insurance during different time intervals. This measure can be used as a proxy measure to determine how experience affects the adoption decisions of producers. Positive values on the graph indicate that a higher percentage of producers opted to seed HT canola. The figure shows the tendency for producers in the midrange of farming experience – i.e., those enrolled in crop insurance for between 10 and 20 years – to adopt HT canola. Producers who have participated in crop insurance for less than 10 years or more than 30 years were less likely to adopt HT canola.



Note: Positive values indicate a higher percentage of HT producers.

Figure 2.4 - Percentage difference of producers adopting HT canola at specified CPI levels, HT minus non-HT producers, Manitoba, 1995-2000.



Note: Positive values indicate a higher percentage of HT producers.

Figure 2.5 - Percentage difference in number of producers enrolled in crop insurance each year, HT producers minus non-HT producers, Manitoba, 1995-2000.

The price of the technology is another important factor in producers' adoption decisions. Table 2.2 depicts a cost comparison of the three commercially available HT canola systems, as well as the conventional system using 2003 suggested retail pricing (SRP).

From the table, the average costs of HT canola systems are all less than the seed and chemical cost for producing conventional canola. For an individual producer, this relationship (i.e., HT systems less expensive that non-HT) may not hold true. Notice from Table 2.2 that the seed costs and chemical costs for each system are reported over a range of prices. While traditional canola has the highest average cost of any system, it also has the widest range of costs. When compared to the three HT systems, traditional canola has the lowest cost in the range, significantly below that of any of the other three systems. Traditional canola also has a significantly higher cost in its range as compared to the three HT systems.

The cost of the canola system, itself, is affected by many factors of the individual producer. Seed costs vary with the individual variety chosen. Canola breeders, as with breeders of other crops, continuously try to improve upon crop performance. New varieties are continuously being bred for improved yield, increased disease resistance, different climatic regions and other factors. As new and improved varieties come onto the market, older varieties tend to become less expensive, if they are still commercially available. The individual producer chooses the variety that will best serve to maximize his or her objective function – whether that be to increase yield, decrease chance of disease or extend canola production to non-traditional growing regions.

The chemical cost component within the price of a canola system will vary largely on the amount and type of weed infestation the producer needs to control. While there are limited chemical choices for the HT systems, options to control weeds in conventional canola are more plentiful. Higher weed infestations are assumed to cost more to control. Table 2.2 provides one example of a chemical combination that could be used. Again, depending on the weed control required, there are both more and less expensive options available to the producer.

Table 2.2 - 2003 Canola System Cost Comparison

Inputs	Clearfield	Roundup Ready	Liberty Link	Conventional
Seed:				
Common Varieties	46A76, 45A71, Hylite 289 & 292	LG3235, 3455, 3311, Hyola 505, 512, 45H21	Invigor brands – 2573, 2733, 5020, 5030	Hyola401, Q2, 46A65, Ebony
Seed Rate (lbs/ac)	5.5	5.96	5.5	5.75 - 6.2*
Price ($/lb)	3.85 – 4.27	2.50 – 6.25	5.80 – 6.25	1.00 – 4.50
Price per acre	*21.17 – 23.49*	*14.90 – 37.25*	*31.90 – 34.37*	*5.75 – 25.88***
Chemical:				
Product(s)	Absolute *or* Pursuit Ultra	Glyphosate†	Liberty	Edge *&* Trifluralin
Application Rate	Abs – 17.3g/ac Odyssey 0.17L/ac Lontrel PU – 0.07L/ac Pursuit 0.19L/ac Poast Ultra	0.67 – 1.0 L/ac	0.54 - 1.6L/ac	Edge – 6.9 – 11.3 kg/ac Trifluralin – 0.65 – 0.81L/ac
Price ($/ac)	*26.07 – 32.99*	*7.30 – 9.79*	*7.40 – 15.30*	*23.01 – 52.14*
Technology Use Agreement ($/ac)	None	$15	None	None
Per Acre Cost	**47.24 – 56.48**	**37.20 – 62.04**	**39.30 – 49.67**	**28.76 – 78.02**
Average System Cost ($/ac)	**51.86**	**49.62**	**44.49**	**53.39**

*Conventional varieties are recommended at 6.2 lbs per acre, with the exception of Hybrids, which are recommended at 5.75 lbs per acre

**Only Hybrid conventional varieties are priced at $4.50 per lb., thus the maximum cost for seed would be 5.75 lbs. per acre x $4.50 per lb. = $25.88 per acre.

†With the expiry of the Monsanto's patent on Roundup, there are many glyphosate products on the market that can be used with the Roundup Ready system.

Source: Saskatchewan Agriculture, Food and Rural Revitalization (2004); Manufacturer's Suggested Retail Pricing;

2.1 Summary

This chapter has examined the characteristics of canola producers in the province of Manitoba for the years 1995 through 2000 to determine the potential differences between adopters and non-adopters of GM technology. Data from Manitoba Crop Insurance allows an examination of adoption patterns with respect to soil type, management ability, experience and risk. This data suggests that producers of HT canola in Manitoba can typically be categorized in the following manner: they tend to farm in less productive soils (such as the *I* or *J* soil zones); they are less productive in canola production, as measured by the canola productivity index; and they tend to have a moderate level (10 to 20 years) of farming experience (neither the least nor the most experience).

The comparisons conducted in this chapter give support to the theory that differing characteristics of producers is potentially one explanation for the incomplete adoption of HT canola. The goal in the remaining portion of this thesis is to test this theory by developing a conceptual model for adoption that accounts for varying characteristics, and then implementing the model in an empirical analysis. Prior to consideration of the conceptual component of this thesis in Chapter 4, Chapter 3 provides a brief look at previous studies which have estimated producer returns from agricultural innovations.

3 LITERATURE REVIEW

Adoption and diffusion of innovations are necessary conditions for technological change to occur. There is often a considerable gap between the time when an innovation is made available, and the time that it becomes widely used. Rogers' (1962) work was some of the first to suggest that diffusion of innovations is an *S*-shaped curve which is a function of time. The *S*-shape illustrates a function which depicts a process where the rate of adoption essentially moves from 'zero' – prior to initial adoption – to 'zero' – where adoption of the innovation ceases. The initial period depicts adoption at a relatively low rate; this initial period is followed by a take-off period where the potential market is penetrated to a large extent in a relatively short period of time. A period of saturation follows the take-off, where diffusion rates of the innovation slow. At the point when diffusion peaks, adoption rates approach zero. Often, there is also a period of decline, when one observes obsolescence of the technology as it is potentially replaced by another innovation or the number of potential adopters is exhausted.

Factors that influence individuals' decisions to adopt new innovations have been the focus of many studies attempting to explain the adoption behavior. Mansfield (1961) and others suggested that adoption and diffusion occurred as a result of imitation, where contact with others spurs the spread of the technology. A key assumption in imitation models of adoption is that producers are homogeneous. David (1975) and others relaxed the assumption of homogeneous producers in the threshold model of adoption. The threshold model contributes an important aspect to adoption modeling not captured in the imitation model – the assumption that producers are heterogeneous in their production practices, and will adopt technologies as a function of their individual characteristics. Once an innovation has been adopted the returns from its generation and introduction – at all levels, from innovator to producer – can be estimated. A significant number of studies have estimated the returns to new agricultural cropping technologies (Griliches, 1958; Nagy and Furtan, 1978; for an overview, see Alston, Norton and Pardey, 1995). Traditional analyses of new agricultural innovations were relatively straightforward. The public nature of R&D facilitated empirical estimation of benefits and returns because of the transparency of information. This transparency allowed economists to estimate the effects of a new technology throughout the supply chain, from innovator to producer.

One characteristic of public innovations is that they are typically priced competitively (i.e., at marginal cost of production of innovation). Innovations resulting from publicly funded research and supplied competitively to downstream competitive producers are often drastic innovations, or innovations that are priced below the old technology and completely take over the market. Welfare measures for competitively supplied innovations and the returns to agricultural R&D are relatively straightforward.

With an increasing amount of private investment in the agricultural input industry, primarily with respect to agrochemical and seed development, traditional welfare and returns-to-research analyses have become much more complex. One reason is that information has become less transparent given the private nature of the R&D. A second reason for this complexity is the introduction of intellectual property rights (IPR) protection. One characteristic of IPRs, such as patents, is that those firms who hold them can exert (limited) monopoly power over the price of the innovation the IPR is protecting. If the IPR-protected innovation is supplied to a previously competitive market, innovations are more likely to be non-drastic, even if they are supply-inducing (Moschini and Lapan, 1997).

A non-drastic innovation occurs when both technologies co-exist in the market. While the monopolistic innovator can set price to effectively capture the benefit producers would see from a supply increase in their production, setting the price any higher than the pre-existing, competitively supplied technology would deter producers from adopting the new innovation. Producers are effectively faced with (relatively) the same price for both technologies, and both will exist in the market.

Literature surrounding adoption theory, including a brief discussion of adoption modeling, will be discussed in Section 3.1. Studies which consider traditional methods of estimating returns to producers, specifically from canola production, are examined in Section 3.2. Recognizing that the benefits from adopting herbicide tolerant technology cannot be estimated in the same way because of the private nature of its development, studies that have considered the returns to adopting privately funded agricultural innovations will be reviewed in Section 3.3.

3.1 Adoption and Diffusion of New Innovations

There has been considerable study done on the processes of adoption and diffusion of new innovations in the economic literature. Numerable works have attempted to chronicle the proposed theories regarding the process of adoption, including: Rogers (1962, 1983); Davies (1979); Mahajan and Peterson (1985) and Stoneman (2002). Many of these reference the pioneering works of Griliches (1957) and Rogers (1962), each of whom proposed a model depicting diffusion of innovations through a system as a function of time.

Figure 3.1 provides an illustration of the process of diffusion as proposed by Griliches (1957) and Rogers (1962), which is still widely accepted today. The key feature of the illustration in Figure 3.1 is the *S*-shape of the curve. This curve shows that when an innovation is first introduced, adoption occurs very slowly; both the number of adopters and the rate of adoption are low. Adoption increases quickly, or “takes off” when approximately 10 to 25 per cent of the population has adopted the innovation. This rapid increase generally continues until approximately half of the

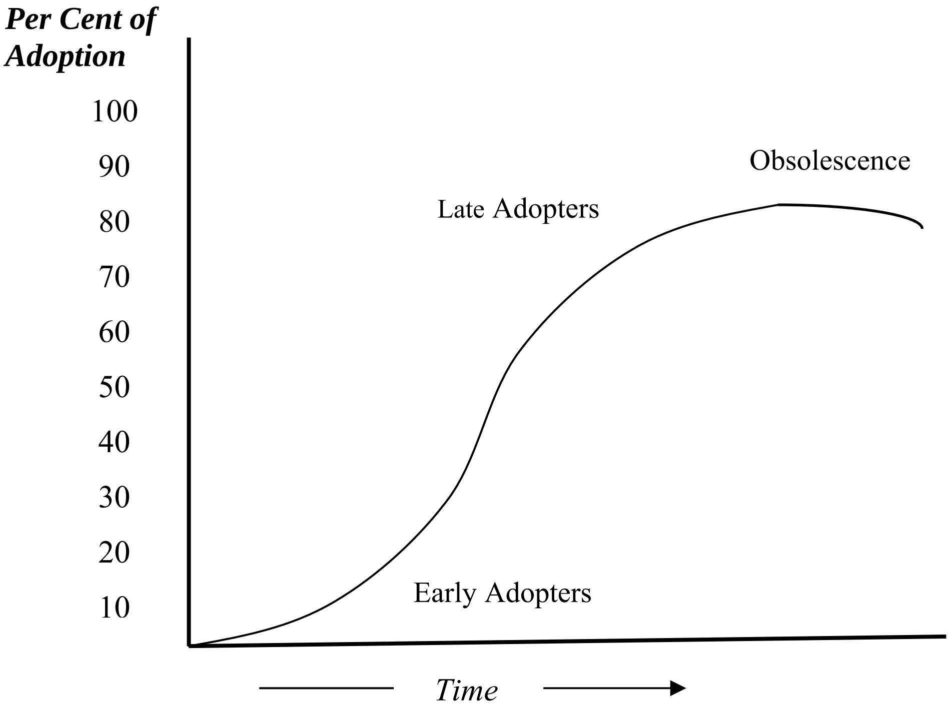


Figure 3.1 - Diffusion of Innovations
Source: Rogers (1962)

population has adopted, at which time the rate of adoption slows down as fewer and fewer individuals adopt (Rogers, 1962).

While the process of adoption as a function of time is generally widely accepted, there are many theories as to what causes adoption to occur. Heiman *et al.* (2000) cite imitation – the process by which an individual learns by word of mouth or by observing another individual's behavior – as one of the reasons. Mansfield (1961) developed a mathematical model which depicts adoption as a result of imitation. In this model, if X_t represents the portion of producers who have adopted the innovation by time t, then the change in aggregate adoption in period t can be written as

$$\frac{\partial X_t}{\partial t} = bX_t\left(1 - \frac{X_t}{k}\right),$$

where b is the acceleration factor and k is the maximum level of diffusion. This equation, referred to as the motion of diffusion by Heiman *et al.* (2000), depicts the dynamic nature of diffusion. It shows how marginal diffusion in time t is proportionate to both realized diffusion and unutilized potential for diffusion. The solution to this differential equation results in an *S*-shaped diffusion curve, as represented by $X_t = k\left[1 + e^{-(\alpha + \beta t)}\right]^{-1}$.

Ghadim and Pannell (1999) concur with the imitation aspect of adoption and state that the smaller the distance from and the greater the frequency of contact with adopters by non-adopters will further stimulate adoption. Beyond contact with adopters, learning by doing and the impact of the learning on producers' personal perceptions of a technology further encourage diffusion of the innovation.

While the imitation model accounts for differing rates of diffusion, it does not explicitly explain what motivates producers to adopt a new technology at different times. One critical assumption in the imitation model is that producers, or firms, are homogeneous. Mansfield (1963) relaxed the assumption that producers are uniform and utilized characteristics of the firm such as size, growth rate, liquidity, expected profitability from the innovation, attributes of management personnel (such as age) and past profits to predict the timing of introducing a new innovation. Kislev and Shchori-Bachrach (1973) also assumed producers were differentiated, and proposed a theory in which the timing of technological change is a function of the skill set in a market. According to Kislev and Shchori-Bachrach's model, early adopters are highly skilled and entrepreneurial. As the technology diffuses, it does so down the 'skill scale', implying that late adopters are lesser skilled.

Threshold models, first introduced by David (1975), and revisited by Heiman *et al.* (2000), also account for heterogeneity among individuals. Threshold models note that if producers are varied across some production attribute such as farm size, management capability, or agronomic factors, for example, then at any moment there is a threshold that will differentiate between adopters and non-adopters of the innovation. The threshold level changes as economic conditions – such as an increase in profits – change.

Graphically, the idea of threshold levels can be shown in Figure 3.2. In the figure, curve B_t^{NT} represents the benefit that different producers receive from the introduction of a new technology. Producers are differentiated according to the attribute A, which is graphed on the horizontal axis. The attribute A could represent features such as soil type or risk attitude – each point on the horizontal axis thus represents a different producer. The mass of producers has been set equal to one so that the proportion of the population can easily be identified.

The downward slope of B_t^{NT} indicates that the benefit derived from the technology decreases as the level of the differentiating attribute is increased. The downward slope on B_t^{NT} thus captures the idea that the benefits of the new technology differ across individuals. Let B^E be the benefit producers receive from the existing technology in time period t. This benefit is assumed to be constant across all producers.[2] Under these conditions, a threshold point exists at point A_t. Producers located to the left of A_t benefit from the adoption of the new technology, since $B_t^{NT} > B^E$. To the right of the threshold A_t are producers who remain better off by not adopting.

Extending the analysis to the next time period illustrates how a reduction in the threshold level can induce further adoption and diffusion of the innovation. Over time, technologies often become better and cheaper as the firms developing them achieve economies of scale. A reduction in the cost of obtaining the technology over time is captured by a shift from B_t^{NT} to $B_{t'}^{NT}$, resulting in the percentage of producers adopting the technology rising to A_t'.

Changing producer perception of technologies may also reduce the threshold level and lead to further adoption. However, there needs to be some mechanism which triggers the change in perception. For the results of the threshold model to apply, Heiman *et al.* express the caveat that adoption will only occur if producers assess a new technology at the time when the economic conditions for them to adopt are right. In practice, producers do not constantly assess new technology, and are often not informed that new technologies exist.

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[2] The assumption of identical benefits to all producers is made to facilitate the graphical exposition and can easily be modified.

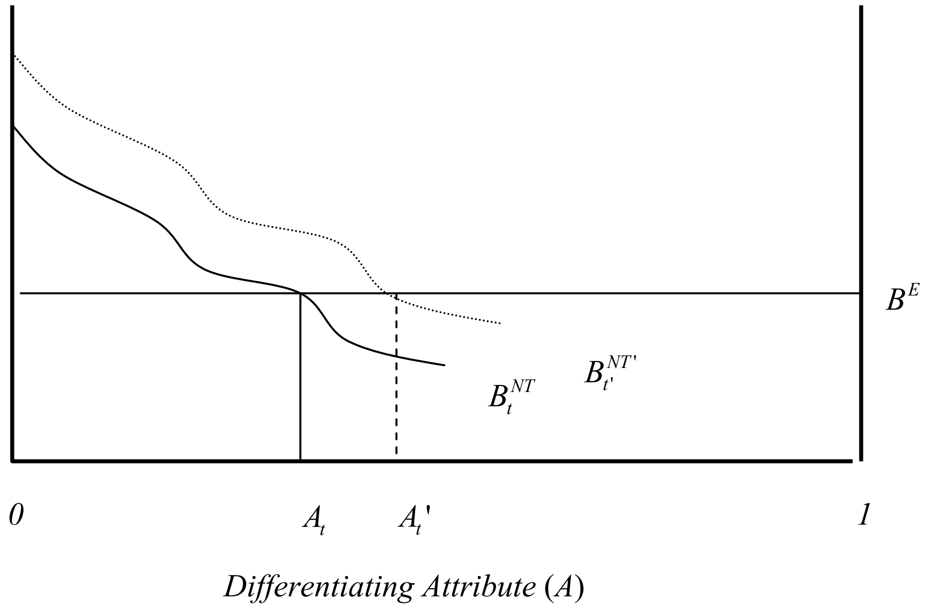

Figure 3.2 - Change in Threshold Adoption Level

For adoption to be consistent with the threshold model (i.e. at any given moment there is a threshold level that distinguishes adopters from non-adopters, as given by the *x*-axis in Figure 3.2), there must be some continuous means to stimulate producers to adopt the technology at any given time. This is where the theories of imitation and threshold modeling interact. A wide body of the adoption literature has suggested that imitation and extension activities contribute to producers' knowledge of new technology. Extension activities generally focus on early adopters, and therefore trigger adoption of a technology. Once employed by early adopters, other producers observe use of the technology by someone with similar characteristics to their own – for example, someone with similar soil type or employing the same type of tillage system – and those producers are then more likely to invest in the technology themselves. In this way, imitation acts motivates diffusion dynamic, and is still consistent with threshold theory.

A key to the above explanation is that the diffusion dynamic arises because of the differentiated characteristics of producers. Differences in timing of adoption by producers occur because there is at least some dissimilarity in characteristics from one producer to the next at any point in time. Given this explanation, the *S*-shape of the diffusion curve in Figure 3.1 will arise when the benefit producers realize changes at a constant rate over time (Heiman *et al.*, 2000).

3.2 Producer Benefits from Canola Production

Production of canola in Canada dates back to the Second World War and the use of rapeseed oil as a machine lubricant. Producer interest in the production of this commodity increased with the subsequent development of crushing and extraction facilities in the 1950s and 1960s. Rapeseed proved to be a viable alternative to cereal crops and allowed producers some diversity in their crop rotation. Increased interest in the crop spurred a large breeding effort to enhance the qualities of the plant for human consumption – until 1960 its uses were mostly limited to industrial applications. With the late 1960s advent of rapeseed varieties with decreased levels of erucic acid and glucosinolates – the components harmful to humans and animals – the industry adopted the term 'canola' in the late 1970s to enhance the image of this new commodity to the consumer (Phillips *et al.,* 2001).

The breeding effort that has been expended on canola is quite impressive (see Khachatourians *et al.* (2001) for a more detailed examination). The pioneering study which examined the returns to the breeding program was conducted by Nagy and Furtan in 1978. Using a Marshallian producer and consumer surplus approach to measure the social gains made from the development of rapeseed varieties, the authors found there to be a 101 per cent return on investment. From their estimation, 53 per cent of this gain accrued to consumers, with producers receiving the remaining 47 per cent.

Ulrich *et al.* (1984) re-estimated the Nagy and Furtan study over a longer period (from 1951-1982); this study was followed by a study by Ulrich and Furtan (1985) for the period 1951-1983. These studies found there to be a fifty and fifty-one percent internal rate of return, with producers laying claim to sixty-eight and sixty-five per cent of the gains, respectively. Over the approximately 30 year period analyzed in both studies, canola production had not yet proliferated to other countries, but was an export commodity for Canada. One difference in the results of the Ulrich *et al.* and Ulrich and Furtan studies is due to the consideration of foreign consumers in the 1985 study, who were estimated to receive four per cent of the benefits.

Over the next decade, canola became one of the world's premium oils, and a significant export commodity for Canada. Gray and Malla (2000) considered the distribution of returns to the investment made by the Rapeseed Association of Canada specifically to improve the quality of canola, under the assumption that yield (and thus supply) would be compromised. The study found that the increased perception of canola as a healthy alternative to substitutes such as palm oil increased the demand for canola. However, the reduction in yield from earlier varieties of rapeseed was found to increase the per-unit cost of production for canola. Analyzing these effects over the 1960 to 1992 period in a three-region world model led the authors to the conclusion that the increase in demand outweighed the increase in cost of production. The effort to increase quality led to an overall economic gain, with producers benefiting in all three regions (Gray and Malla, 2000).

Until the mid 1980s, canola research was largely publicly funded. In the late 1980s and the early 1990s, canola research was driven more by private investment and increased interaction between the seed and chemical markets (Phillips *et al.,* 2001). These factors culminated in the commercial release of the first transgenic canola varieties in 1995. The primary trait expressed by those first varieties of transgenic canola was herbicide tolerance. Since then, many other varieties of herbicide tolerant canola have been made commercially available – many as a result of privately funded research. As Section 3.3 shows, privately funded R&D in the presence of intellectual property rights (IPRs) significantly changes how the benefits from an innovation accrue to producers. While there has not been any significant work on the benefits to producers from using HT canola, there have been numerous studies estimating the impacts from the adoption of other agricultural innovations resulting from private R&D.

3.3 Impacts from Adoption of Privately Funded Agricultural Innovations

The introduction of intellectual property rights (IPRs) as an impetus for private research and development significantly changed how the distribution of benefits from adoption of an agricultural commodity should be analyzed. The presence of IPRs allows private companies undertaking R&D and subsequently distributing the innovations to exert market power in the industry. Fulton (1997) and Moschini and Lapan (1997) discuss the implications of IPRs on the distribution of returns to innovation. One important observation is that, due to the nature of the goods produced, IPRs have the ability to create oligopolistic industries.

Moschini and Lapan (1997) show how imperfect competition in the input supply sector changes the analysis of benefits from the case where technologies are supplied competitively. Figure 3.3 shows the pre-innovation supply curve, or marginal cost of production, given by S_o, which is a function of the competitive price of the input w_o and output price p. Producers realize a pre-innovation benefit equal to area ***B*** in Figure 3.3. With the introduction of a more efficient technology, the post innovation supply curve shifts out to $S_1^{'}$. This new curve is a function of output price p and w_1, the competitive price of the more efficient input. Under traditional analysis, the benefits to the resulting innovation would then be measured directly from this new curve, and is equal to area *(C+**D**)* in Figure 3.3.

Moschini and Lapan argue that due to the presence of IPRs, innovating firms are able to exert market power over the price of the innovation. The ability to exert market power enables the innovating firm to set price so that some or all of the benefit producers obtain from the new technology is captured. There are two possibilities for the innovating firm with market power. The innovating firm may find it optimal to set the price of the new technology (adjusted for the increase in productivity) equal to the price of the old technology. Since the prices of the new and old technologies are equal, only some of the market will be captured, and the technology is non-drastic. Producers will receive no benefit from adopting the new technology. Alternatively, the innovating firm may find it optimal to set the price of the new technology below the price of the old technology. In this case, the innovator will be able to capture the entire market, and the technology is drastic. Producers will receive the benefit of the lower cost of the input.

If the profit maximizing price of the new technology is found to be higher than that of the old technology, then this constraint becomes binding – at any price higher than that of the old technology, the new technology will not be adopted. Producers would see no difference in price between the two technologies (i.e., $w_1=w_o$) and S_1 would directly coincide with S_o. The result is that adoption of the new innovation will not be complete, and the old and new technologies will co-exist – i.e., the technology is non-drastic. Although the increased efficiency of the technology would normally have shifted supply curve outward to $S_1^{'}$, the increase in the price of the innovated input (w_1), supplied non-competitively, shifts the curve back inward. The resulting supply curve, S_1, now approximates the old supply curve, S_0.

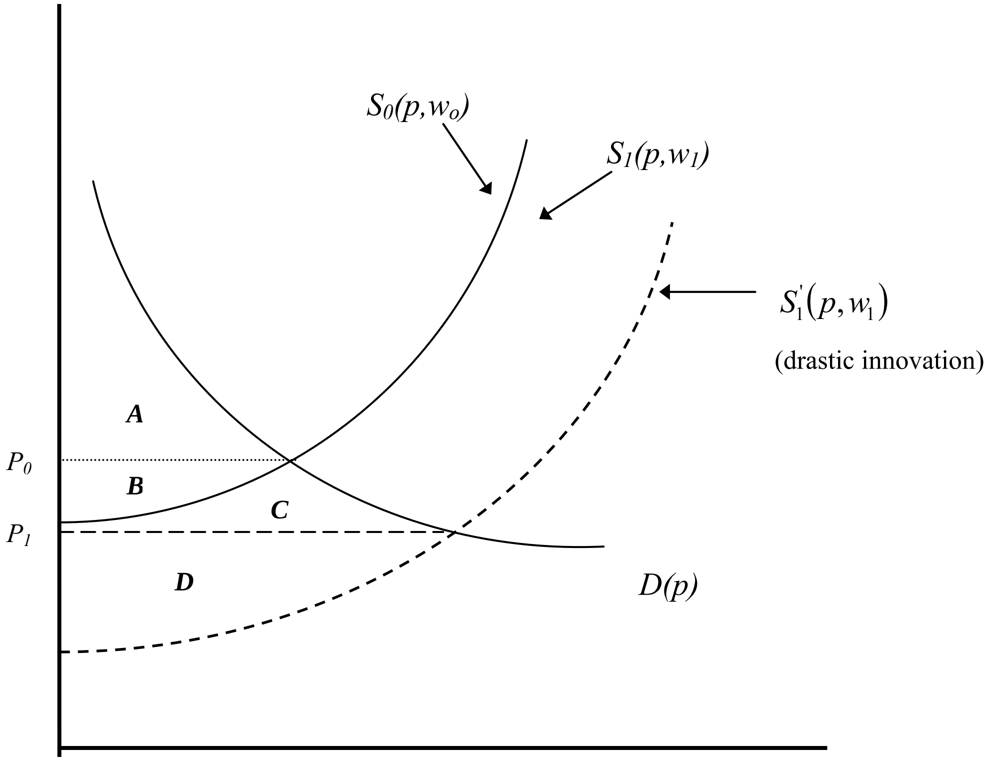

Figure 3.3 - Effect of non-competitive input pricing

The scenario presented in Figure 3.3 allows both the old and new technologies to coexist in the market. The innovation is thus termed 'non-drastic'. The innovation would be deemed 'drastic' if the price of the new technology was set sufficiently below the price of the old technology so that it completely takes over the market. In this case, the relevant supply curve would be S_1', as producers would effectively see a decrease in their cost of production due to a lower input price, w_1. All producers would find it more profitable to use the new technology and the technology would be completely adopted. Fulton and Giannakas (2002) show, in detail, the conditions under which drastic or non-drastic innovation will emerge.

Several studies have considered the returns to non-competitively supplied innovations under the assumption of monopolistic (or oligopolistic) power in the input market.[3] Moschini *et al.* (2000) extend the analysis of Moschini and Lapan to assess the impact of adopting Roundup Ready© soybeans in an open economy setting. The results of this study show that producers in the home country (i.e., the country developing the technology) lose surplus due to spillover effects when the technology is adopted in competing countries. However, the magnitude of the loss is diminished if producers in foreign countries are subjected to strong IPRs (i.e., foreign producers are required to pay the same markup – such as a technology fee – as are domestic producers).

Falck-Zepeda *et al.* (2000*a*) consider the adoption of Bt cotton in the United States in 1996. Using the economic surplus model developed by Moschini and Lapan (1997) and extended to an open economy, the study used cost of production data to estimate the distribution of surplus between consumers, producers and innovators. The study found that the innovation resulted in a first-year increase in world surplus of US$240.3 million. Of this surplus, US cotton producers received 59 per cent of the increase.

The returns in the second year of Bt cotton planting, as well as preliminary estimates of the returns to HT soybeans in the US are examined in Falck-Zepeda *et al.* (2000*b*). Using the same methodology as in Falck-Zepeda *et al.* (2000*a*), returns to Bt cotton adoption were re-estimated at US$164.9 million in 1997, with only 42 per cent of this increase accruing to domestic US producers. In the case of HT soybeans, it was estimated that US producers received between 29 per cent and 76 per cent of the surplus generated by adoption, depending on the estimates of supply elasticity that were used.

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[3] Several studies have addressed the issue of returns to innovations in imperfectly competitive markets when the output market downstream of the innovating production sector is able to exert market power. Huang and Sexton's (1996) assessment of producers adopting mechanical tomato harvesters in Taiwan in the presence of oligopsonistic procurement is one example. Alston *et al.* (1997) examined the size and distribution of research benefits when processors are able to exert both oligopsonistic power in purchasing raw commodity from the producer and oligopolistic power in selling processed farm products.

3.4 Summary

There is a large body of literature relative to the adoption of new technologies. Early examinations of adoption focused on imitation by others who have already adopted the technology. Subsequent studies suggested threshold theory was a more robust means of modeling innovation adoption and diffusion, as it recognized that all producers differ in their production characteristics. Producers can differ in terms of such things as farm size, agronomic practices employed, geography, age, education and management ability. Threshold theory maintains that at any point in time, over a set of producer characteristics, there is a threshold level which distinguishes adopters from non-adopters of the technology. There has been some suggestion that imitation may be the impetus for technologies to diffuse beyond early adopters, as others' perception of the technology changes with observation. Learning by doing has also been cited as a method that facilitates diffusion of an innovation.

Once an agricultural innovation has been adopted, the impacts of its adoption can be estimated. The evolution of canola from a non-edible industrial commodity (rapeseed) to a product known for its premium oil qualities for human consumption and further as one of the first widely distributed and commercially produced products of biotechnology is an excellent example of innovation. This chapter has reviewed some of the economic assessments of canola as it evolved under both a publicly and privately motivated research agenda.

Under publicly conducted R&D, estimates of the returns to rapeseed (and then canola) research over an approximate 30 year span – from the 1950s to the 1980s – range from approximately 50 per cent to 101 per cent. Producers have received between 47 and 67 per cent of these gains, with consumers laying claim to the rest.

With increasing involvement of private money into research the distribution of the gains becomes different. New technologies have been seen to decrease cost of production to producers, but theory suggests the production sector might not see the same returns to research as it did during times of public research. The presence of IPRs has allowed private innovating companies to price their innovations (seed and chemical) non-competitively, and thus to capture the benefits of a lower cost of production at the farm level. Despite this prediction, empirical estimates of the returns to biotechnological innovations – in particular to HT soybeans and Bt cotton – suggest that producers receive between 30 and 70 percent of the returns to research.

The literature reviewed in this chapter has suggested that there are some benefits to producers from using cost-reducing technologies that have resulted from privately funded research. To date, there have been no empirical estimates specifically on the returns to producers from adopting HT canola, a product of privately funded research. Chapter 4 will consider a conceptual model that will attempt to identify adopters of HT technology in canola from non-adopters. Chapter 5 will empirically test the model developed in Chapter 4, and extend the results to an analysis of the gross returns to producers from adoption of HT canola.

4 ESTIMATING PRODUCER BENEFITS

While HT technology has been widely accepted, it has not been completely adopted by Canadian canola producers (see Chapter 1) or Manitoba canola producers (see Chapter 2). The fact that this technology has not been fully adopted suggests that it is a non-drastic innovation. As indicated in Chapter 3, the benefits that accrue to producers under a non-drastic innovation are quantitatively different than those under a drastic innovation. Chapter 2 points out that producers may differ in a number of characteristics (e.g. soil zone, management ability, risk aversion) and that these differences appear to be correlated with the adoption of HT technology. Thus, it is critical to consider producer heterogeneity when examining the adoption of HT technology.

The purpose of this chapter is to develop a conceptual model which specifically considers adoption of a new technology as a function of the characteristics of the adopters. Section 4.1 develops a (mathematical) conceptual model based on threshold theory to explain the adoption decision of producers over time. Section 4.2 builds upon the threshold model and develops a model that considers an estimation of the returns to producers from the adoption of HT canola.

4.1 Threshold Model of Adoption of HT canola

Several studies have considered varying characteristics among producers as factors in adoption of innovations similar to HT canola. Tauer (2001) estimates the impact on profits of dairy producers adopting or not adopting recombinant bovine somatotropin (rBST). A dummy variable regression is used to estimate profits as a function of technology use and farmer characteristics. Tauer acknowledges the potential for self-selection bias to exist in his model, as producers who adopt rbST may generally be more or less profitable, even without the technology. To correct for this bias, Tauer employs a binary probit analysis to determine adoption of rbST as a function of producer characteristics. The probit analysis regresses age, education, business organization and farm size on the decision of producers to adopt or not adopt rbST technology. Modified results of the probit analysis are then included in the dummy variable regression to account for selection bias.

Fernandez-Cornejo *et al.* (2001) examine factors affecting the adoption of two technological innovations, genetically engineered crops (specifically corn and soybeans) and precision agriculture systems. The authors employ a censored choice tobit model to distinguish between the adoption decision and the intensity, or extent, of adoption by controlling for one characteristic – farm size. One model is estimated for each technology – HT soybeans, HT corn, Bt corn, and precision agriculture. In each model, the authors regressed the extent of adoption against proxy variables for those factors assumed to influence the adoption decision.

For the models concerning genetically engineered crops, Fernandez-Cornejo *et al.* define the extent of adoption as, "…the proportion of total harvested corn (soybean) acres in herbicide-tolerant corn (soybeans), as well as the proportion of total corn acres in Bt corn." In the model estimating precision agriculture adoption, the extent of adoption is defined as, "…the proportion of total crop acres on which the variable rate technology (VRT) was applied for seeding, fertilizing or applying chemicals." The factors influencing adoption in all models include farm size, producer risk attitudes, level of education, experience, off-farm employment, land tenure, credit reserves, farm typology, use of contracting, degree of pest infestation, and region. The authors present their results as decomposed elasticities to show how responsive current users, non-users and the sum of both are to changes in farm size.

Payne *et al.* (2003) assessed the likelihood of corn producers adopting the corn rootworm (CRW) Bt technology by considering the influence operator and farm socioeconomic characteristics would have on expected adoption. The paper employed an ordered logit model, and considered factors such as operator age and education, farm size, specialization in corn production, crop rotation, current technology use, current CRW infestation, geographic location, off-farm labor and current CRW management practices to estimate the probability of adoption. Factors that were found to positively influence the likelihood of adoption included age of operator, farm size, significant current infestations (or expected infestations) of CRW, experience with corn borer Bt technology and specialization in corn production (i.e., derived greater than 50 per cent of the operation's value of production from corn). Off-farm income had a negative affect on expected adoption, as did the location of farms in the eastern Corn Belt of the United States.

Barham *et al.* (2004) examined the dynamic adoption of recombinant bovine somatotropin (rBST) technology in Wisconsin and identified producer characteristics that would distinguish between early and late adoption, as well as non-adoption and dis-adoption (defined as discontinued use of the technology). The study found that non-adopters were distinct in terms of their characteristics, having smaller operations, lower use of complementary technologies and possessing relatively negative views toward technology, as compared to adopters or dis-adopters. The only distinguishing characteristics revealed in the analysis relative to early and late adopters and dis-adopters were attitude toward the technology and use of complementary technologies. The study did not find overwhelming evidence that there would be further significant adoption of the rBST technology in Wisconsin, which plateaued in 2001-02.

Burton *et al.* (2003) employ Duration Analysis to consider the effect of both economic and non-economic characteristics of producers on the adoption of organic horticultural technology in the United Kingdom. Duration Analysis allows both adoption and diffusion of an innovation to be analyzed simultaneously by considering the timing of adoption in a dynamic context. While the study found that gender and attitudes toward environmentalism and sustainability were influential factors in the decision to adopt, duration analysis found that for some conventional producers, the probability of adoption 'degenerated' rapidly. That is, the predicted time for adoption to occur for an individual producer exceeded the expected time over which that producer was still likely to be farming.

4.2 Modeling Producer Adoption of HT Canola

For the purposes of this thesis, which specifically considers the characteristics of producers which would lead to adoption or non-adoption of HT canola, the threshold model will be employed. Recall the threshold model developed graphically in Figure 3.2 which suggests that a producer will adopt the technology when the economic benefit to do so is right, depending upon the individual's characteristics. Mathematically, the threshold model can also be described in terms of the probability of producers adopting the new technology. Producers will benefit from the adoption of HT technology when $B_t^{NT}(A) > B^E$, where $B_t^{NT}(A)$ explicitly denotes that the benefits of the new technology are a function of the producer attribute *A*. The term B^E denotes the benefits of the existing technology. Suppose that the benefits of the new technology are uncertain, i.e. $B_t^{NT} = \overline{B}_t^{NT} + \varepsilon$ where $\overline{B}_t^{NT}$ is the expected benefit, and *ε* is an error term with mean zero. The probability of an individual with attribute *A* adopting the technology is given by

$$P\left[\overline{B}_t^{NT}(A) + \varepsilon\right] > B^E. \tag{4.1}$$

Rearranging 4.1 indicates that the probability of an individual with attribute *A* adopting is

$$P(\varepsilon) > B^E - \overline{B}_t^{NT}(A), \tag{4.2}$$

i.e., the probability of adopting is given by the probability of the error being greater than the difference between the benefit from the existing technology and the expected benefit from the new technology.

The model presented above carries the implicit feature that the variable of interest – adoption of a technology – can take either a yes ($Y = 1$) or no ($Y = 0$) response; that is, the dependent variable is dichotomous. Models of this nature are referred to as discrete choice models. Following Greene (2000), the decision to adopt ($Y = 1$) or not adopt ($Y = 0$) can be depicted as

$$\Pr(Y = 1) = F(A, \boldsymbol{\beta})$$
$$\Pr(Y = 0) = 1 - F(A, \boldsymbol{\beta})$$

where ***A*** is the vector of differentiating factors such as risk attitude, management and experience that explain the adoption decision; β is a set of parameters accounting for the changes in ***A*** on the probability of the decision; and *F* represents a continuous probability distribution.

The probability decision can, thus, be modeled as a regression:

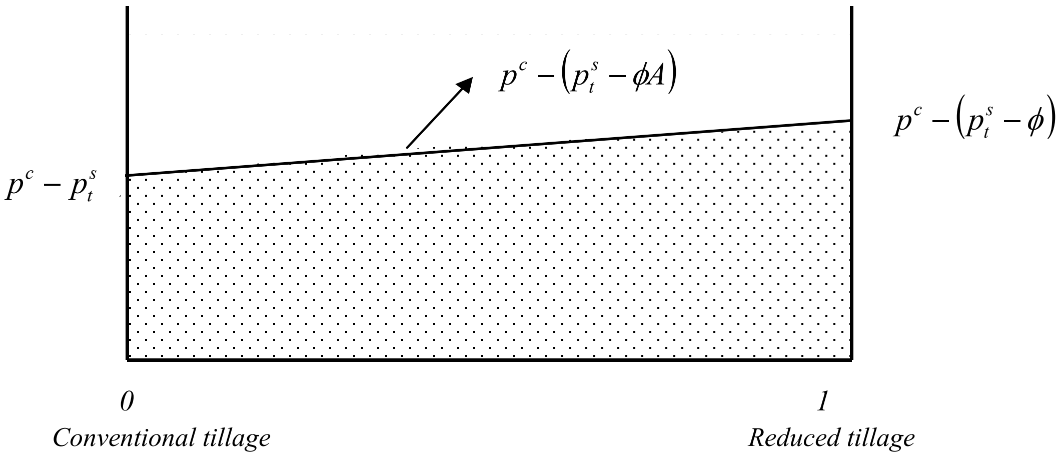
$$\begin{aligned} E\left[y|\mathbf{A}\right] &= 0\left[1 - F\left(\boldsymbol{\beta}'\ \mathbf{A}\right)\right] + 1\left[F\left(\boldsymbol{\beta}'\ \mathbf{A}\right)\right] \\ &= F\left(\boldsymbol{\beta}'\mathbf{A}\right). \end{aligned} \tag{4.3}$$

While this model can be estimated using any continuous probability distribution, it is important that the underlying theory being tested is supported by the resulting predictions. Common distributions used in discrete choice analysis include the normal distribution, which gives rise to the probit model, and the logistic distribution, resulting in the logit model.

4.3 Estimating Producer Returns from the Adoption of an Innovation

The threshold model provides key insights into the adoption patterns of producers. The idea that there is a point of differentiation among producers at which they will either adopt or not adopt a new technology can be extended to an analysis of the benefits producers receive from the adoption of an innovation. Fulton and Keyowski (1999) develop a model which accounts for producer heterogeneity and differing adoption patterns to assess the benefit to producers from adopting a new technology – herbicide tolerant canola. The model will be discussed in detail, as it will provide the basis for the empirical analysis in this thesis.

If producers are assumed to be differentiated according to some characteristic, or combination of characteristics, then they can be expected to receive net returns from their production as depicted in Figure 4.1. Suppose producers are differentiated with respect to an attribute such as the type of tillage system they employ. Producers are distributed along the horizontal axis from left to right according to the degree of reduced tillage that they use. For instance, those producers who use a conventional method of tillage and do not employ any type of conservation tillage practices can be located to the left of the diagram. At the right side of the diagram are located those producers who have adopted reduced tillage practices. Those at the extreme right use zero-tillage technology.



Differentiating Attribute (A)

Figure 4.1 - Net Returns from an Existing Technology

The assumption is made that those producers who have adopted reduced or minimum tillage practices will receive a higher net return from the production of their commodity – in this case canola – than will those who have not adopted such methods. For the purposes of this model, net returns prior to adoption of HT canola, the innovation, are given by the equation $p^c - (p_t^s - \phi A)$, where p^c is the price of canola, p_t^s is the price of the seed and chemical package, A is the differentiation attribute and ϕ is a cost reduction parameter. The producer who uses conventional tillage – i.e., the producer with $A = 0$ – realizes a net return of $p^c - p_t^s$. Returns for the producer who has adopted a zero tillage method – i.e., the producer with $A=1$ – is given by $p^c - p_t^s - \phi$. Note that the less the tillage system disturbs the soil, the higher are the returns. Total returns to the production of traditional canola are represented by the shaded area of Figure 4.1. Note that because returns are higher for those producers who use reduced tillage practices, producers have the incentive to invest capital into these types of systems.

The introduction of an innovation, in this instance HT canola, is shown in Figure 4.2. As in the case of traditional canola, the assumption is made that those producers who adopt HT canola and employ reduced tillage practices will receive higher returns than those producers who adopt the HT technology but retain conventional tillage practices. Net returns from the adoption of HT canola are given by the equation $p^c - p^s_{ht} - \gamma A$, where p^c is the price of canola, p^s_{ht} is the price of the seed and chemical package, A is the differentiation attribute and γ is a cost reduction parameter. The producer who uses conventional tillage – i.e., the producer with $A = 0$ – realizes a net return of $p^c - p^s_{ht}$. Returns for the producer who has adopted a zero tillage method – i.e., the producer with $A=1$ – is given by $p^c - p^s_{ht} - \gamma$. Total returns to the production of HT canola are represented by the total shaded area of Figure 4.2, less area **B**.

From Figure 4.2, it is obvious that producers who use conventional tillage are better off using the old technology. Producers who have adopted a reduced tillage system corresponding with A^* are indifferent between the old and new technologies. Producers who employ a tillage system to the right of A^* benefit more from the use of HT canola, with those located on the extreme right receiving the most benefit. An important aspect of this framework is that although not all producers adopt HT canola, there are benefits to be had by those who do adopt. Since adopters receive an additional benefit over that obtained from the production of the old technology, overall benefit to the market is increased.

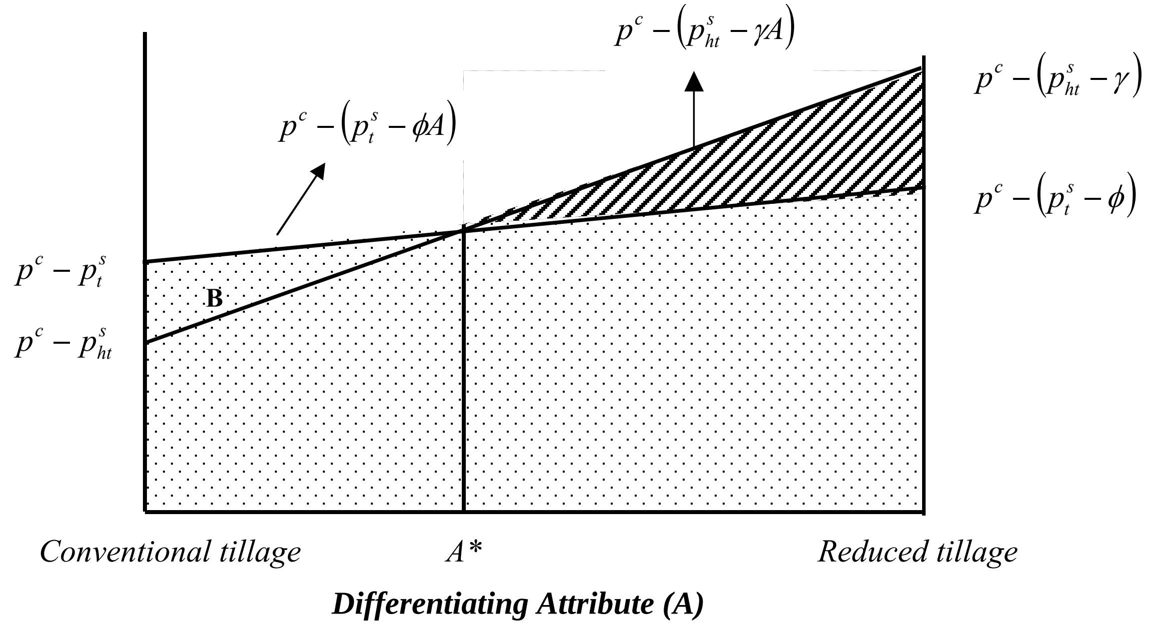


Figure 4.2 - Net Returns from Adopting a New Technology

Comparative statics can easily be carried out using the above model. A reduction in the price of traditional seed will, *ceteris paribus,* increase the benefit of using the traditional technology – an effect that can easily be seen by shifting the $p^c - (p^s_t - \phi A)$ curve upward. The upward shift of this curve also exemplifies the effect of the price of traditional seed on the production of HT canola. Specifically, fewer producers will adopt the technology, and fewer benefits will be had from its use.

A change in the price of the new technology will also, *ceteris paribus,* affect the benefits producers realize from its adoption. Notice that as the price of HT canola seed increases, the benefits to producers decrease (this can be shown as a downward shift of the $p^c - (p^s_{ht} - \gamma A)$ curve). If the price of HT seed is sufficiently high there will be no benefit from the use of the innovation and no producers will adopt. Such a situation would occur if the net returns line for new technology lies everywhere below that of the old technology. Therefore, pricing of the technology is an import aspect to consider.

The framework developed above can easily be incorporated into the adoption probability model outlined in section 4.1. Assuming the benefits of the new technology are uncertain, the benefits can be written as

$$\pi = p^c - \left(p_{ht}^s - \gamma A\right) + \varepsilon \tag{4.4}$$

Substituting equation 4.4 depicting the benefits from production of traditional and HT canola into equation 4.1 results in

$$P\left[p^c - \left(p_{ht}^s - \gamma A\right) + \varepsilon\right] > p^c - \left(p_t^s + \phi A\right). \tag{4.5}$$

By rearranging equation 4.5, the probability of HT canola being adopted is given by

$$P(\varepsilon) > p^c - \left(p_t^s + \phi A\right) - p^c - \left(p_{ht}^s - \gamma A\right)$$

$$\Rightarrow P(\varepsilon) > \left(p_{ht}^s - p_t^s\right) + (\gamma - \phi)A\,. \tag{4.6}$$

The term $p_{ht}^s - p_t^s$ in Equation 4.6 captures the benefits producers realize from the new technology. Generally, the probability of adopting is affected by the cost of the technology and the yield a producer expects to achieve from adopting the technology.

The term $(\gamma - \phi)A$ captures the cost reduction an individual can realize from using the new technology, based on his individual characteristics such as management ability, risk aversion and experience. The benefit producers see from using the technology will be influenced directly by the set of characteristics they possess.

4.4 Summary

This chapter develops a conceptual framework which determines the probability of adopting an innovation based on producers having different characteristics. From this theory a model is developed which specifically concerns the adoption of HT canola. The analysis shows that while some producers benefit from the adoption of HT canola, others remain better off by retaining the old technology – conventional canola. Comparative statics show that producers are less likely to adopt HT canola (and thus less likely to benefit from its use) when the price of traditional seed is low, or when the price of HT seed is sufficiently high.

The results of this chapter form the basis for the analysis in Chapter 5. The analysis in Chapter 5 is twofold. An estimation of expected yields as a function of soil type, growing conditions and variety of canola is conducted in stage one of the analysis. The assumption is that expected yield is one factor that will determine a producer's probability of adopting HT canola. The estimation of expected yields will then be employed in a logit model, along with other factors such as producer experience, risk aversion and productivity rating to estimate the probability of adoption.

5 EMPIRICAL MODEL AND RESULTS

The previous chapter outlined a conceptual model concerning the adoption of HT canola when producers are assumed to be heterogeneous. There are many characteristics which differentiate producers. Differentiating factors which influence the decision to adopt a technology include experience, attitudes toward risk and the producer's expectation on the performance of the technology, among others. In the context of this thesis, the effective influence of these factors in combination culminates in the producer's decision to either adopt or not adopt HT canola technology. An empirical estimation concerning the impact of the factors influencing adoption thus needs to take place in the context of a limited dependent variable (LDV) model. The logit model is one type of LDV that can be used to estimate the effect of differentiating factors on the probability of a producer adopting HT canola.

Data provided by Manitoba Crop Insurance Corporation (MCIC) is used in the empirical estimation, and is collected at the individual producer level. This data includes the choice of technology a producer has made (i.e., HT or non-HT canola), individual risk profiles, experience and an index of individual producers' productivity in producing canola. Section 5.1 discusses the data used in the empirical analysis conducted in this chapter.

Another important factor in the adoption decision – which is not included in the MCIC dataset – is the yield a producer expects to obtain from the adopted technology. Estimation of expected canola yields will be conducted in Section 5.2. The results from this estimation will then be used, along with the differentiating factors outlined above, in a logit model to determine each factor's effect on the likelihood of adoption. The logit analysis will be carried out in Section 5.3. Results of the two stage estimation are presented in Sections 5.4 and 5.5.

5.1 Data and Sources

The data used in this thesis were obtained from the producer reported information database of Manitoba Crop Insurance Corporation (MCIC). The data is collected at the individual producer level from the years 1995 through 2000. The data set consists of 124,566 cross-sectional observations of yield.

The data required for the estimation of expected yields, given by equation (5.1), include the year of production, the type of technology and soil zone. Varietal data is used to identify technology type. The variable representing the technology type receives a one for each yield estimate that corresponds to a herbicide tolerant variety, and a zero otherwise. In 2004, there are approximately 294 canola varieties registered for use in Canada.

When the data from MCIC were initially analyzed in the OLS regression for estimated yield, it was found that certain varieties were strongly statistically significant. Upon further inspection of the data it was found that these varieties were, in fact, outliers – varieties with very few observations with uncommonly high (or low) yield observations attached to them. To ensure that these outliers did not bias the results, varieties with observations less than the mean number of observations per variety were eliminated.[4] Given the large number of observations available, removal of these varieties should not compromise the integrity of the analysis. Thus, the model includes 51 varieties. Varietal information is captured using 50 dummy variables. A complete listing of canola varieties registered for use in Canada and their corresponding technology is presented in Appendix A. Those varieties utilized in this thesis are indicated.

Soil type, as reported by Manitoba Crop Insurance, is classified on a rating scale of *A* through *J*. These classifications are based on a 35-year average yield index for wheat, oats and barley on benchmark soils within Manitoba. The

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[4] The mean number of observations per variety when all varieties are considered is 396. Those varieties removed represent both new and old technology.

benchmarks are classified according to their productivity – class *A* being the highest yielding soils and class *J* being the lowest yielding. For the purposes of this analysis, each class (with the exception of class *J* which is used as the reference class) is defined as a dummy variable in the model.

Data for producer experience, management ability, risk aversion, producer expectations and gross costs are used to estimate the probability of producers choosing to produce HT canola. The qualitative factors used in the estimation, including experience, management ability and risk aversion are estimated using MCIC-supplied information as proxy variables. Producer experience is accounted for by using the number of years the individual has been enrolled in crop insurance as the proxy. A larger number of years enrolled corresponds to a larger degree of experience. Risk aversion can be measured using crop insurance coverage levels as the proxy. These levels range from 50 to 80 per cent (with intermediate levels in increments of ten per cent) of the producer's probable yield (as calculated by MCIC). Producers who insure at higher levels (i.e., 80 per cent) are assumed to be more risk averse than those producers who insure at lower levels. Management ability is explained through each producer's canola productivity index (CPI), as calculated by MCIC. The CPI is an annual productivity index of an individual's canola yield, expressed as a percentage of the average of the risk area in which he resides.[5] An individual's productivity index is averaged using a maximum of the 10 most recent years of available production data.[6] For each soil zone, the individual's index (individual yield as percentage of area average) is averaged across his reported acres for that soil zone. The result is a weighted annual index, by crop. The CPI (specific to canola) and IPI (a more generalized index calculated for individuals across all commodities) are unique calculations to Manitoba Crop Insurance Corporation, derived from a producer's Harvested Production Report.

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[5] Manitoba Crop Insurance (2001*b*) defines a risk area as an area of common production risk. Areas with similar soils and/or climates are placed within the same group.

[6] Using a maximum of ten years of available production data is consistent with how crop insurance calculates insurable yields, and takes into consideration the change that cropping technology, such as the introduction of zero tillage, will have on productivity.

The gross costs used in the estimation of the model are the manufacturer's suggested retail prices (SRP) as given in Table 2.2. Chemical SRPs were obtained from Saskatchewan Agriculture Food and Rural Revitalization's annual publication *Guide to Crop Protection.*[7] The suggested retail prices for seed were obtained as quotes from seed dealers. Many of the SRPs for both chemical and seed are reported on a per unit basis, and are therefore converted to a per acre basis for the analysis. Seeding rates are those suggested by the Canola Council of Canada (2001) for each system. Chemical application rates used in the calculation of chemical costs are those suggested by Saskatchewan Agriculture Food and Rural Revitalization (2004). The chemical application rates are assumed constant across years. The prices of seed and chemical, however, are variable from year to year as new product becomes available, and as weed control requirements change. Averaged chemical costs from the data reported in Table 2.2 will be used in the analysis, and are based on the manufacturers' suggested retail price for the specific variety of canola under analysis.

5.2 Regression Model for Estimating Expected Yields

This section develops an empirical model to determine expected yields of canola. Per acre yield can be expected to be a function of factors such as soil type, year of production, the technology (i.e., HT) and variety. Variety information is an important factor to consider, as it allows examination of yield differences between varieties, as well as between HT and non-HT canola.

The model to estimate per acre expected yield is specified as a linear function of the form:

$$y_i = \alpha + \sum_{j=1}^{9} \beta_j D_{sz_i} + \sum_{k=1}^{5} \delta_k D_{yr_i} + \sum_{m=1}^{9} \gamma_m \left(D_{ht} \cdot D_{sz}\right)_i + \sum_{p=1}^{5} \eta_p \left(D_{ht} \cdot D_{yr}\right)_i + \sum_{v=1}^{50} \lambda_v D_v \qquad (5.1)$$

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[7] While the prices used in the analysis are from a Saskatchewan publication, they are the manufacturers' suggested retail prices, which are comparable across the Prairie Provinces.

where y is yield, D_{sz} $(sz = 1,...,9)$ are dummy variables denoting soil zone; $D_{yr}(yr = 1,...,5)$ are dummy variables indicating the year in which the yield observations were obtained; $(D_{ht} \cdot D_{sz})$ $(ht, sz = 1,...,9)$ and $(D_{ht} \cdot D_{yr})$ $(ht, yr = 1,...,5)$ are the interaction terms between HT and soil zone and year, respectively; and, D_v $(v = 1,...,50)$ is a varietal dummy variable.

The model is estimated using ordinary least squares (OLS). Excel canola (a non-HT variety) in the *J* soil zone of Manitoba in 1995 is the base to which all other estimates of yield are relative.

There are other variables that will affect the yield of canola that are not specifically included in the model to estimate expected yield. Primary factors that have been omitted from the model include weather (i.e., precipitation) and the type of tillage system used (i.e., conventional vs. zero-tillage). A producer's choice to fertilize more or less intensively, and the choice and application rate of chemicals are endogenous variables that are not explicitly stated in the model, but may be captured in a producer's management profile.

5.3 Regression Model for Estimating the Probability of Adoption

The second stage of estimation examines the probability that an individual producer will adopt HT canola. A producer's decision to adopt HT canola is influenced by many factors including the individual's experience, risk profile, productivity and expectations on the performance of the technology.

Since the decision to adopt is a discrete choice, an estimation of the probability of adoption is dependent on the nature of the error term contained in the analysis (recall equation 4.5). There are several types of limited dependent variable models that can be used, depending on how the error term is assumed to be distributed. In the case where the error term is assumed to be logistically distributed, the model can be estimated using logit analysis, as is done here.

The logit model is applied to:

$$\begin{aligned} z_i = {} & \alpha_i + \beta_1 x_{risk_i} + \beta_2 x_{\exp_i} + \beta_3 x_{mgt_i} + \beta_4 x_{\exp yld_i} + \beta_5 x_{\cos t_i} + \sum_{k=1}^{5} \beta_k \cdot D_{Y_{ki}} + \sum_{m=1}^{5} \beta_m \left(x_{risk} \cdot D_{Y_m} \right)_i \\ & + \sum_{n=1}^{5} \beta_n \left(x_{\exp} \cdot D_{Y_n} \right)_i + \sum_{r=1}^{5} \beta_r \left(x_{mgt} \cdot D_{Y_r} \right)_i + \sum_{t=1}^{5} \beta_t \left(x_{\exp yld} \cdot D_{Y_t} \right)_i + \sum_{v=1}^{5} \beta_v \left(x_{\cos t} \cdot D_{Y_v} \right)_i + \varepsilon_i \end{aligned} \tag{5.2}$$

where z_{it} is a limited dependent variable that receives a 1 for HT and a 0 for non-HT production; x_{risk} is a crop insurance coverage level representing risk aversion; x_{exp} is the number of years a producer has been enrolled in crop insurance and is used as an experience proxy; x_{mgt} is the producer's canola productivity index (CPI), a proxy for management ability; x_{expyld} is the expected yield of canola estimated from Stage 1 of the analysis, as per Section 5.2 ; and x_{cost} represents the gross cost (encompassing the cost of seed, chemical and the TUA) for a specific canola system. D_Y (Y=1,…,5) are dummy variables denoting the year corresponding to each observation. The terms $(x_{risk} \cdot D_{Ym})$, $(m=1,\ldots,5)$; $(x_{exp} \cdot D_{Yn})$ $(n=1,\ldots,5)$; $(x_{mgt} \cdot D_{Yr})$ $(r=1,\ldots,5)$; $(x_{expyld} \cdot D_{Yt})$ $(t=1,\ldots,5)$; and $(x_{cost} \cdot D_{Yv})$ $(v=1,\ldots,5)$ are interaction terms between year and the variable for risk, experience, management, expected yield and cost, respectively. The term ε_i is a logistically distributed error term.

The model is estimated using binary logit estimation. All results of the regression on the probability of adopting HT canola are compared to the base year, 1995.

Since the coefficients calculated in the logit regression do not have the same interpretation as the marginal effect, or slope, in a linear regression, the marginal effect of each of the independent variables must be calculated. The marginal effect shows the effect of a change in a regressor on the probability of producers adopting HT technology. Following Greene (2000), this effect can be determined by

$$\frac{\partial E[y|x]}{\partial x} = \left\{ \frac{dF(\beta' x)}{d(\beta' x)} \right\} \beta = f(\beta' x) \beta . \tag{5.3}$$

Berndt (1991) indicates that, for estimates of a logit model, $f(\cdot)$ is closely approximated by the ratio $P(1-P)$, where P is the proportion of adopters. Thus, the marginal effects are given by

$$\frac{\partial E[y|x]}{\partial x} = P(1-P)\beta \qquad (5.4)$$

This equation, however, does not apply to calculating interaction effects in discrete choice models. Following the work of Norton, Wang and Ai (2004), the interaction effect in discrete choice models is determined by

$$\frac{\partial F(u)}{\partial x_1 \partial x_2} = \beta_{12}\left[F(u)(1-F(u))\right] + (\beta_1 + \beta_{12}x_2)(\beta_2 + \beta_{12}x_1)\left[F(u)(1-F(u))(1-2F(u))\right] \quad (5.5)$$

where β_{12} is the coefficient of the interaction term and *F(u)* (the cumulative density function) is closely approximated by *P,* the proportion of HT observations in the sample.[8]

5.4 Yield Estimation Results

Equation (5.1) is estimated using the Ordinary Least Squares (OLS) method provided by Eviews. The results from the yield estimation are shown in Table 5.1. The estimate for the constant, α, is statistically significant at the five per cent level. All estimates for soil type are statistically significant at the five per cent level, and are positive, indicating that each soil type positively affects the yield of canola, from approximately two bushel per acre to 12 bushel per acre over the *J* soil type. The coefficients decrease from *A* to *J*, indicating consistency with the description of soil classification in the previous section – i.e., *A* soils are the most productive, while *J* soils are least productive. All of the HT-soil interaction terms are negative, indicating that the HT technology and soil type interact to decrease yields relative to the base yield. All but one of these interaction terms are statistically significant (seven are statistically significant at the 5 per cent level and one at the ten per cent level).

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[8] For the case where one continuous variable is interacted with a dummy variable, as is the case in this thesis, another much more complicated formula exists. However, due to time limitations and difficulty in using this formula the standard formula provided is used. Please see Norton, Wang and Ai (2003) for more detail about this formula, which provides a more accurate approximation of the interaction effect when one continuous and one dummy variable interact.

Each of the year estimates are statistically significant, while only three of the five interaction estimates between HT and year are statistically significant – two at the five per cent level and one at the ten per cent level. All but three of the variety estimates – those for Vanguard, Bullet and Trojan – are statistically significant at either the five or ten per cent levels. Of the 50 varieties in the estimation, only four are negative, indicating that 46 varieties have a yield advantage over Excel canola in the *J* soil zone.

The results of this analysis can be used to compare varieties for the same location, during the same production year. To obtain the predicted yields for use in these comparisons, the coefficients of interest are added together. For example, the expected yield for Innovator (a HT canola) in the *D* soil in 1998, is 26.98 bushels per acre, while the expected yield for Hyola 401 (a non-HT hybrid canola) in the same year and soil type is 34.44 bushels per acre. In this case, the non-HT variety has a higher expected yield than the HT variety.

To account for varietal influence on yield, comparisons can be made between specific HT and non-HT varieties. Twelve varieties, six non-HT and six HT – two from each type of HT system - were chosen for analysis. The varieties chosen were the most widely used in Manitoba as determined by the number of observations of each variety in the data-set. Figure 5.1 summarizes six expected yield comparisons between non-HT and HT varieties for all soil zones (*A* to *J*) for the years 1995 through 2000. Positive values on the charts reflect a yield advantage for the HT variety.

Table 5.1 - Stage 1: OLS Estimation Results

Variable	**Coefficient**	**(t-value)**
Intercept	12.99	(18.89)*
Year		
1996	7.10	(57.8)*
1997	1.69	(13.11)*
1998	3.85	(27.42)*
1999	6.70	(42.6)*
2000	0.46	(2.71)*
Soil Zone		
A	12.19	(16.07)*
B	7.48	(10.92)*
C	9.45	(13.93)*
D	8.63	(12.72)*
E	6.84	(10.09)*
F	5.73	(8.41)*
G	5.65	(8.22)*
H	3.94	(5.62)*
I	1.94	(2.55)*
HT-Year		
HT-1996	-0.85	(-1.78)
HT-1997	-0.05	(-0.10)
HT-1998	-1.82	(-3.89)*
HT-1999	-1.83	(-3.84)*
HT-2000	0.40	(0.82)
HT-Soil		
HT-A	-2.08	(-1.99)*
HT-B	-1.44	(-1.56)
HT-C	-2.68	(-2.95)*
HT-D	-2.38	(-2.62)*
HT-E	-2.45	(-2.70)*
HT-F	-2.25	(-2.47)*
HT-G	-2.48	(-2.70)*
HT-H	-2.79	(-2.97)*
HT-I	-1.89	(-1.86)
Variety		
44A89	2.98	(6.43)*
45A50	8.91	(8.08)*
45A51	10.61	(10.29)*
45A71	7.44	(7.34)*
46A05	2.10	(6.52)*
46A65	8.09	(41.88)*
46A72	7.44	(7.10)*
46A73	9.80	(9.26)*
46A74	9.41	(8.51)*
46A76	13.43	(12.92)*
Agassiz	9.02	(19.95)*
Arrow	6.67	(6.46)*
Bounty	-1.85	(-4.28)*
Bullet	-0.51	(-1.35)
Conquest	9.65	(26.78)*
Coronet	4.03	(12.43)*
Crusher	3.70	(17.41)*
Cyclone	1.94	(5.40)*
Defender	3.91	(14.33)*
Dynamite	4.81	(16.14)*
Ebony	8.08	(39.09)*
Elect	2.20	(5.68)*
Exceed	6.45	(6.17)*
Garrison	1.25	(5.30)*
Global	7.39	(21.02)*
Hudson	4.26	(11.77)*
Hyola 401	8.14	(48.9)*
Impact	2.21	(6.85)*
Independence	6.29	(6.07)*
Innovator	5.71	(5.58)*
Invigor 2153	11.59	(11.26)*
Invigor 2273	12.62	(12.28)*
Jewel	4.15	(14.03)*
Legacy	2.15	(10.8)*
Legend	-0.71	(-2.18)*
LG3235	11.62	(11.18)*
LG3295	8.60	(8.33)*
LG3310	7.30	(21.27)*
LG3345	10.34	(9.59)*
LG3455	8.62	(21.87)*
Magnum	2.89	(6.65)*
PGS 3850	10.55	(10.21)*
PGS 3880	11.61	(10.97)*
Profit	-3.43	(-5.95)*
Promark	6.58	(19.33)*
Q2	5.29	(13.62)*
Quantum	3.54	(19.35)*
Quest	9.56	(9.36)*
Stallion	4.34	(4.47)*
Trojan	-0.14	(-0.39)
Vanguard	0.30	(0.94)

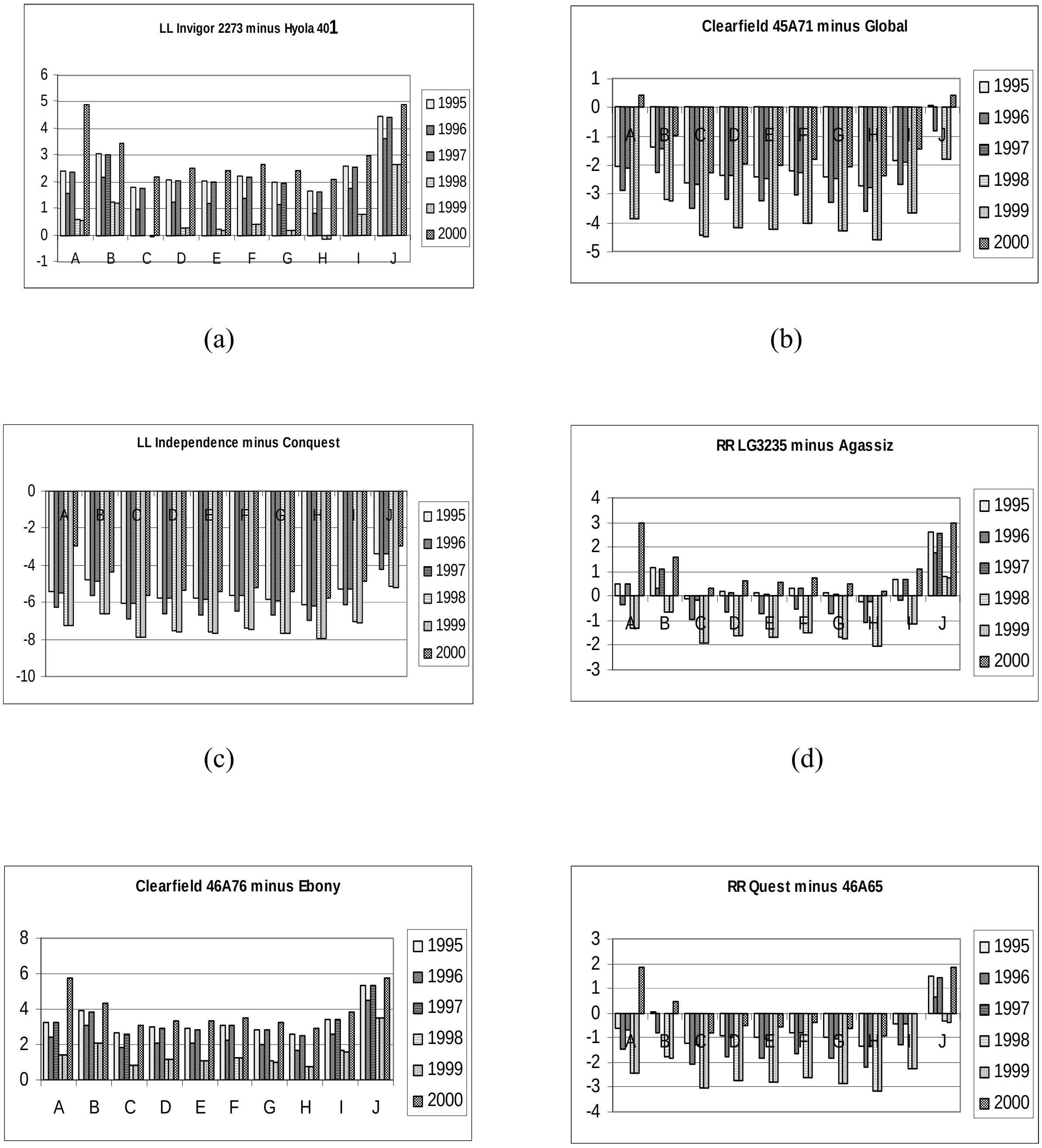
N = 124,566

Adj. $R^2 = 0.202$

Panel *(a)* in Figure 5.1 shows the comparison between Liberty Link® (LL) *Invigor 2273* and a non-HT hybrid variety, *Hyola 401.* The LL variety has a yield advantage in nearly all years and soil zones with the exception of the *H* soil zone in both 1998 and 1999. Clearfield® (CL) *45A71* is outyielded by the non-HT variety *Global* in panel *(b),* except for the 2000 crop year in the *J* soil zone. Panel *(c)* shows a yield advantage for non-HT *Conquest* in all soil zones in all years over the Liberty Link® variety *Independence*. This is the only comparison in which a non-HT variety always yields better than the HT variety under comparison. Roundup Ready® (RR) *LG3235* exhibits varying yield advantages over non-HT *Agassiz* across both soil zones and crop years. The one comparison in which the HT variety outyields the non-HT variety in all soil zones, over all years is shown in panel *(e)* – Clearfield® *46A76* compared with non-HT *Ebony.* The comparison between RR *Quest* and non-HT *46A65* in panel *(f)* exhibits much the same results as panel *(d)*, in which neither variety dominates all of the time.

The comparisons in Figure 5.1 are representative of the performance of each HT variety in comparison with the other non-HT varieties under consideration. Several observations can be made from these comparisons. First, the conventional varieties performed better in 1998 and 1999. In the comparisons where there is an HT advantage, the advantage seems to be smaller for those two years within a given soil zone. When the non-HT variety is shown to have a yield advantage in 1998 or 1999, the advantage seems to be larger than the advantage is in other years for the same soil zone.

Second, HT canola performed better in 2000. Consider panels *(b), (d)* and *(f)*. For the soil zones where there is a yield advantage displayed, the advantage most often occurs in the 2000 crop year. Third, HT varieties seem to perform better in the extreme soil zones (i.e., *A* and *J*), while non-HT varieties do better in the mid-range soils. This third observation is consistent with the assumption that lower-productive land (i.e., the *J* soil) may have higher weed infestations, and the HT varieties perform better with the ability to non-selectively control weeds in-crop. The more productive *A* soils may tend to be colder and more difficult to get onto earlier in the spring for pre-seeding weed control. Again, the ability to non-selectively control weeds in-crop in this instance would lend to the better performance of HT varieties.



(a) (b)

(c) (d)

(e) (f)

Note: Positive values indicate HT yield advantage.

Figure 5.1 - Yield Differences Across Soil Zones, Selected Varieties, 1995-2000

Table 5.2 depicts the statistical significance of the yield comparisons shown in Figure 5.1. To test for statistical significance, a Wald coefficient restriction was placed on the yield comparisons. Specifically, the following null hypothesis was tested:

$$H_0: \quad \left.\begin{array}{l} \beta_1 + \delta_j + \gamma_1 + \eta_j + \lambda_{v_1} = \beta_1 + \delta_j + \lambda_{v_2} \\ \beta_2 + \delta_j + \gamma_1 + \eta_j + \lambda_{v_1} = \beta_2 + \delta_j + \lambda_{v_2} \\ . \\ . \\ . \\ \beta_{10} + \delta_j + \gamma_1 + \eta_j + \lambda_{v_1} = \beta_{10} + \delta_j + \lambda_{v_2} \end{array}\right\} j = 1,...,6$$

Where $\beta_i, i = 1,...,10$ represents the coefficient corresponding to the soil zone in which the yields are being compared; $\delta_j, j = 1,...,6$ is the coefficient corresponding to the year in which the comparison takes place; γ represents the interaction coefficient between the HT technology and soil zone; η is the interaction coefficient between the HT technology and year; and, v_1 and v_2 represent the coefficients corresponding, respectively, to the HT and non-HT variety being compared. The restriction tests whether the expected yield estimate for HT canola – the left hand side of the equation – is equal to the expected yield estimate for non-HT canola – the right hand side of the equation. The restrictions can be reduced to:

$$H_0: \quad \left.\begin{array}{l} \gamma_1 + \eta_j + \lambda_{v_1} = \lambda_{v_2} \\ \gamma_2 + \eta_j + \lambda_{v_1} = \lambda_{v_2} \\ . \\ . \\ . \\ \gamma_{10} + \eta_j + \lambda_{v_1} = \lambda_{v_2} \end{array}\right\} j = 1,...,6$$

While the alternative hypothesis is:

$$H_A: \quad \left.\begin{array}{l} \gamma_1+\eta_j+\lambda_{v_1}\neq\lambda_{v_2} \\ \gamma_2+\eta_j+\lambda_{v_1}\neq\lambda_{v_2} \\ . \\ . \\ . \\ \gamma_{10}+\eta_j+\lambda_{v_1}\neq\lambda_{v_2} \end{array}\right\} j=1,\ldots,6$$

The reported values allow a test of the hypothesis that the expected yield differences for all soil zones in any given year are equal to zero. The critical *F* value at the five per cent confidence level for 124,566 observations and ten restrictions is 1.83. From Table 5.2 it is clear that all yield differences are statistically significant at the five per cent level. The conclusion to draw from these results is that yield differences appear to exist between HT and non-HT varieties.

Table 5.2 - Statistical Significance of Yield Differences, Selected Varieties, 1995-2000.

Year	**LL Independence versus Conquest**		**LL Invigor 2273 versus Hyola 401**		**RR Quest versus 46A65**		**RR LG3235 versus Agassiz**		**CF 46A76 versus Ebony**		**CF 45A71 versus Global**	
	F value	Stat. Sig.	*F value*	Stat. Sig.	*F value*	Stat. Sig.	*F value*	Stat. Sig.	*F value*	Stat Sig.	*F value*	Stat. Sig.
1995	14.25	*	6.21	*	5.35	*	5.22	*	8.17	*	6.83	*
1996	26.9	*	6.99	*	9.56	*	5.12	*	9.01	*	11.82	*
1997	26.19	*	14.13	*	7.62	*	5.22	*	15.72	*	9.29	*
1998	40.7	*	5.13	*	34.89	*	6.59	*	6.76	*	18.23	*
1999	39.34	*	5.13	*	30.80	*	6.70	*	6.71	*	17.36	*
2000	24.27	*	20.72	*	5.74	*	5.32	*	23.09	*	7.46	*

**significant at 5 per cent*
$F^{\text{critical}} = 1.83$
K=10
N=124,566

To say whether or not a particular variety exhibits a yield advantage is not an accurate assessment of the benefit to producers from the use of one technology or the other. Because of the difference in cost across the canola systems available on the market, it is not simply yield, but gross returns, that determine the relative benefits to producers.

Table 5.3 shows, in detail, the calculation of estimated gross returns for the *C* soil in 2000. System costs used correspond to those reported in Table 2.2 for the individual variety under consideration. Estimated yields are taken from the regression in stage one of the analysis. Of the varieties being compared, the conventional hybrid, *Hyola 401*, is the most costly to produce at an estimated \$59.34 per acre. The least costly is the LL variety *Independence* at \$33.10 per acre. For the *C* soil of Manitoba, CF *46A76* is the highest returning variety, followed by LL *Invigor 2273,* RR *LG 3235* and the conventional variety *Agassiz*.

Table 5.3 gives a detailed example of how estimated gross returns can be calculated for a given soil zone. Using this same methodology, gross returns can be calculated for each of the other soil zones, by canola system. Estimated gross returns for each soil zone are depicted in Table 5.4 using the estimated yields for 2000. Note that the Clearfield 46A76 system is the highest returning system across all soil zones. Similar to the comparison done for the *C* soil zone, the next highest returning systems are *Invigor 2273* and *LG 3235*. The ranking of the remaining varieties depends on soil type. For example, *Agassiz* is the next highest returning variety in soil zone *B*, while *Quest* is the next highest returning variety in soil zone *A*.

In the same way that yield differences between HT and non-HT varieties were compared in Table 5.2, the statistical significance of gross returns between varieties can also be compared. Table 5.5 shows the statistical significance of the difference in gross returns using the same variety comparisons used in Table 5.2. Again, the reported values are *F* statistics based on Wald coefficient restrictions placed on the difference in gross returns between varieties.

Specifically, the null hypothesis tested is:

$$H_0: \quad \left.\begin{array}{l} (\beta_1+\delta_j+\gamma_1+\eta_j+\lambda_{v_1})\rho_{v_1} = (\beta_1+\delta_j+\lambda_{v_2})\rho_{v_2} \\ (\beta_2+\delta_j+\gamma_1+\eta_j+\lambda_{v_1})\rho_{v_1} = (\beta_2+\delta_j+\lambda_{v_2})\rho_{v_2} \\ . \\ . \\ . \\ (\beta_{10}+\delta_j+\gamma_1+\eta_j+\lambda_{v_1})\rho_{v_1} = (\beta_{10}+\delta_j+\lambda_{v_2})\rho_{v_2} \end{array}\right\} j=1,\ldots,6$$

where $(\cdot)$ are the yield estimates calculated from the regression and ρ_v is the system cost (seed, chemical and technology use fee) for the particular varieties under comparison. The above restrictions can be reduced to:

$$H_0: \quad \left.\begin{array}{l} (\gamma_1+\eta_j+\lambda_{v_1})\rho_{v_1} = \lambda_{v_2}\rho_{v_2} \\ (\gamma_2+\eta_j+\lambda_{v_1})\rho_{v_1} = \lambda_{v_2}\rho_{v_2} \\ . \\ . \\ . \\ (\gamma_{10}+\eta_j+\lambda_{v_1})\rho_{v_1} = \lambda_{v_2}\rho_{v_2} \end{array}\right\} j=1,\ldots,6$$

versus the alternate hypothesis:

$$H_A: \quad \left.\begin{array}{l} (\gamma_1+\eta_j+\lambda_{v_1})\rho_{v_1} \neq \lambda_{v_2}\rho_{v_2} \\ (\gamma_2+\eta_j+\lambda_{v_1})\rho_{v_1} \neq \lambda_{v_2}\rho_{v_2} \\ . \\ . \\ . \\ (\gamma_{10}+\eta_j+\lambda_{v_1})\rho_{v_1} \neq \lambda_{v_2}\rho_{v_2} \end{array}\right\} j=1,\ldots,6\,.$$

The critical *F* value for a five per cent confidence level is 1.83. Notice from Table 5.5 that all comparisons are statistically significant at the five per cent level.

Table 5.3 - Gross Return Comparison, Manitoba *C* Soil Zone, 2000.

	Clearfield		**Roundup**		**Liberty Link**		**Conventional Open Pollinated**					**Conv Hybrid**
	46A76	***45A71***	***LG 3235***	***Quest***	***Independence***	***Invigor 2273***	***Agassiz***	***Conquest***	***Ebony***	***Global***	***46A65***	***Hyola 401***
Gross Returns												
Yield (bu/acre)	34.1	28.1	32.2	30.2	26.9	33.2	31.9	32.6	31.0	30.3	31.0	31.1
Commodity Price ($/bu)	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Expected Gross ($/acre)	**$238.35**	**$196.45**	**$225.72**	**$211.31**	**$188.38**	**$232.71**	**$223.53**	**$227.88**	**$216.92**	**$212.12**	**$217.00**	**$217.38**
System Costs ($/acre)												
Seed Cost	$19.80	$19.80	$19.37	$19.67	$11.00	$20.63	$7.44	$21.75	$10.54	$11.16	$ 14.88	$ 25.97
Herbicide Cost	21.62	21.62	4.90	4.90	22.10	22.10	33.37	33.37	33.37	33.37	33.37	33.37
TUA	N/A	N/A	15.00	15.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total System Cost	**$41.42**	**$41.42**	**$39.27**	**$39.57**	**$33.10**	**$42.73**	**$40.81**	**$55.12**	**$43.91**	**$44.53**	**$48.25**	**$59.34**
Gross Returns ($/acre)	**$196.93**	**$155.03**	**$186.45**	**$171.74**	**$155.28**	**$189.98**	**$182.72**	**$172.75**	**$173.01**	**$167.59**	**$168.75**	**$158.05**

Source: Canola Council of Canada (2001); SAF (2001); author's calculations.

Table 5.4 - Calculated Gross Returns, dollars per acre, 2000.

		A	***B***	***C***	***D***	***E***	***F***	***G***	***H***	***I***	***J***
HT											
Clearfield	46A76	$234.92	$191.91	$196.93	$193.28	$180.31	$173.94	$171.74	$157.61	$149.91	$149.58
	45A71	$193.01	$150.00	$155.03	$151.37	$138.40	$132.03	$129.83	$115.70	$108.01	$107.67
Roundup Ready	LG 3235	$224.43	$181.43	$186.45	$182.79	$169.83	$163.45	$161.26	$147.12	$139.43	$139.09
	Quest	$209.72	$166.72	$171.74	$168.08	$155.11	$148.74	$146.54	$132.41	$124.72	$124.38
Liberty Link	Independence	$193.27	$150.26	$155.28	$151.62	$138.66	$132.29	$130.09	$115.96	$108.26	$107.93
	Invigor 2273	$227.97	$184.96	$189.98	$186.33	$173.36	$166.99	$164.79	$150.66	$142.96	$142.63
Non-HT											
Conventional Open Pollinated	Agassiz	$201.91	$168.95	$182.72	$176.95	$164.47	$156.70	$156.09	$144.17	$130.14	$116.57
	Conquest	$191.94	$158.99	$172.75	$166.99	$154.50	$146.74	$146.13	$134.20	$120.17	$106.60
	Ebony	$192.20	$159.24	$173.01	$167.24	$154.76	$146.99	$146.38	$134.46	$120.43	$106.86
	Global	$186.78	$153.82	$167.59	$161.82	$149.34	$141.57	$140.96	$129.04	$115.01	$101.44
	46A65	$187.94	$154.98	$168.75	$162.98	$150.50	$142.74	$142.12	$130.20	$116.17	$102.60
Conventional Hybrid	Hyola 401	$177.23	$144.28	$158.05	$152.28	$139.79	$132.03	$131.42	$119.50	$105.47	$91.90

Source: Author’s calculations.

Table 5.5 - Statisitical Significance of Gross Returns, Selected Varieties, 1995-2000.

Year	LL Independence versus Conquest		LL Invigor 2273 versus Hyola 401		RR Quest versus 46A65		RR LG3235 versus Agassiz		CF 46A76 versus Ebony		CF 45A71 versus Global	
	F value	Stat. Sig.	*F value*	Stat. Sig.	*F value*	Stat. Sig.	*F value*	Stat. Sig.	*F value*	Stat Sig.	*F value*	Stat. Sig.
1995	14.13	*	5.18	*	6.43	*	5.06	*	6.14	*	9.1	*
1996	26.37	*	5.23	*	14.99	*	5.97	*	6.23	*	17.45	*
1997	25.37	*	6.05	*	14.35	*	6.12	*	8.93	*	14.16	*
1998	40.90	*	8.57	*	57.43	*	8.37	*	5.83	*	26.82	*
1999	39.29	*	8.89	*	49.93	*	8.66	*	5.82	*	25.24	*
2000	23.59	*	8.33	*	10.23	*	4.69	*	12.74	*	10.79	*

** significant at 5 per cent*
K=10
N=124,566

Source: Eviews

5.5 Logit Model Estimation

Adoption of HT canola was estimated using the binary logit estimation program provided by Eviews. The results of the analysis are presented in Table 5.6. Each of the variables for risk aversion, management, experience, expected yield and system cost are estimated in interaction with dummy variables for year to account for the effect of time on the probability of adopting HT canola. The base year (i.e., the year dummy omitted from the analysis) is 1995.

The parameters of a logit analysis cannot be interpreted in the same way as in linear regressions, as they are not a measure of the marginal effect of the parameter on the dependent variable. Further, as noted by Norton, Wang and Ai (2004), the sign on the calculated interaction term may be different than the sign on the estimated coefficient for the interaction term. Therefore, slopes are calculated to determine the marginal effect each variable has on the probability of adoption. The formula for the calculation of the marginal effects is shown in equation 5.4. For this analysis, the marginal effects are calculated at the sample means of the data. Alternatively, the marginal effect could be calculated at each individual observation, and the average of the marginal effects used. As Greene (2000) notes, because the functions are continuous, for large samples (as is the case here) these two methods will yield the same results. The marginal, or slope, effects for each variable are found by multiplying the estimated coefficients $(\hat{\beta})$ by the term *P(1-P)*, where *P* is the proportion of HT observations to the entire sample (Berndt 1991). The slope effects of the interaction terms are found by employing equation 5.5. The results of these calculations are summarized in Table 5.6.

Table 5.6 - Stage 2: Logit Regression Results and Calculated Marginal Effects

Variable	**Estimated Coefficient**	**Calculated Marginal Effect**
C	136.0809	136.0809
RISKLEVEL	0.0062	0.0015
EXPERIENCE	-0.0309	-0.0077
MANAGEMENT	1.2039	0.2978
EXPECTYLD	1.6484	0.4077
SYSTEMCOST	-4.3329	-1.0717
Y96	-7.0815	-1.7515
Y97	38.564	9.5381
Y98	20.1502	4.9838
Y99	-81.8827	-20.2521
Y2000	-115.0782	-28.4624
RISK96	-0.0202	-0.0059
RISK97	-0.0289	-0.0062
RISK98	-0.0189	-0.0035
RISK99	-0.0136	-0.0113
RISK2000	-0.0129	0.0133
EXPERI96	0.0354	-0.0270
EXPERI97	0.0085	-0.0105
EXPERI98	0.0160	0.0600
EXPERI99	0.0316	-0.1538
EXPERI2000	0.0255	1.9516
MANAGE96	0.2467	0.8418
MANAGE97	1.6544	-2.4782
MANAGE98	0.5715	-1.1548
MANAGE99	-0.3805	0.9302
MANAGE2000	-1.0671	-0.4740
EXPYLD96	-0.6091	-4.8189
EXPYLD97	-0.4355	-1.2614
EXPYLD98	-0.9174	-1.4950
EXPYLD99	-1.5634	-2.9711
EXPYLD2000	-1.4203	-4.2793
COST96	0.4419	-0.0156
COST97	-0.6019	0.0851
COST98	0.1636	-3.3366
COST99	3.020	-6.0451
COST2000	3.705	-3.8036

Source: Eviews; author's calculations

As hypothesized by Norton, Wang and Ai (2004), the signs on several of the interaction terms have changed. Those terms are shaded in Table 5.6. As mentioned earlier, the coefficients on RISKLEVEL, EXPERIENCE, MANAGEMENT, EXPECTYLD and SYSTEMCOST represent the effect each of these characteristics has on producers' probability of adopting HT canola in 1995.

The calculated marginal effects show several interesting results. First, as a producer's crop insurance coverage level – or level of risk aversion – increases, the results indicate that he is less likely to adopt HT canola, except in 1995 and 2000. This result could indicate that, in the initial year of adoption, producers viewed HT canola as more risky than non-HT canola and thus were less likely to adopt it the more risk averse they were. As experience with the technology increased, producers may have become more comfortable with the performance of the technology, and in fact found that it reduced their risk rather than increased it. Second, the results show that in 1995 the probability of adopting is smaller the more experience a producer has. Over time, this inverse relationship exists in some years (1996, 1997 and 1999) and not in others (1998 and 2000).

Those producers who are better managers (those with higher values associated with their CPI) were more likely to adopt when the technology was first introduced, as indicated by the positive values for the 1995 and 1996 management interaction terms. However, stronger management ability meant less probability of adopting HT canola over the next four years, except in 1999. This result is consistent with the idea that adoption of the technology was increasingly being undertaken by farmers regardless of their management ability.

A disturbing result is that, in all years but 1995, the probability of producers adopting HT canola decreases as the expectation of higher yields increases. This result is contrary to basic economic intuition that states that as expected yields increase, producers will be more likely to adopt the technology. Last, except for 1997, the probability of adoption decreases as the cost of the canola system increases. This result is consistent with economic theory.

Unfortunately, the statistical significance of the above results cannot be determined at this stage. Since the logit coefficients supplied by Eviews are not the marginal effects, the corresponding standard errors supplied by Eviews also do not apply. As pointed out by Ai and Norton (2003), the calculation of standard errors, and thus the ability to test for statistical significance, is extremely difficult when considering interaction effects in discrete choice models. Due to time limitations, the standard errors (and hence the *t*-statistics) have not been calculated. The result is that the thesis is unable to determine the robustness of the results discussed above.

5.6 Summary

The conceptual framework developed in Chapter 4 to examine the adoption of HT canola when producers are assumed to be heterogeneous is empirically tested in this chapter. The empirical application consists of a two stage analysis. Stage one estimates expected yields, which are assumed to be an important factor that producers consider prior to adopting a new technology. This estimation is conducted as a linear regression. The results of this analysis were then used in an estimation of the gross returns to producers as a measure of the benefit from adopting HT canola.

Stage two of the analysis considers the expected yields calculated in Stage one, as well as variables representing producers' risk attitudes, experience, management capabilities and canola system costs as factors in a logit regression to determine the probability of HT canola adoption. Data for both analyses were obtained from Manitoba Crop Insurance for the years 1995 to 2000.

The results from stage one are highly statistically significant; they show that the HT *Clearfield* varieties potentially have the highest returns of the varieties under analysis. Two important points must be considered for these results to hold. First, the results are dependent on the price of the individual systems. Second, if producers do not use the full spectrum of chemicals on non-HT canola, then the relative costs of these systems will decrease.

Stage two results show, primarily, that over time the probability of adopting HT canola diminishes. For the most part, producers' risk profile, expectations on yield and the cost of the canola system have a negative impact on the probability of adoption. Experience has a negative impact on the probability of adoption in four out of six years, while management positively affects the probability of adoption half of the time. These results suggest that the probability of adoption is influenced by the characteristics of producers. However, due to time limitations and the complicated nature of the calculation of standard errors, these results cannot be tested statistically.

6 SUMMARY AND CONCLUSIONS

This study develops a conceptual framework to determine the probability of adopting HT canola when producers are assumed heterogeneous. The model is based on the framework developed by Fulton and Keyowski (1999), but is modified from a deterministic model to a probabilistic model. The study also considers the gross returns from adopting HT canola. Canola production in Manitoba, Canada is chosen as the region of analysis for the empirical component of the study. This chapter summarizes the major findings, specifies some implications of the study, and suggests areas in which the study is limited.

6.1 Summary and Conclusions

Chapter 2 presents a description of canola producers in Manitoba, Canada. Manitoba is the third largest canola producing province in Canada. In 2002, 74 per cent of total canola acres in Manitoba were devoted to HT canola production. Several factors, such as soil type, producer risk profile, experience, productivity, and management ability are considered as potentially determining adopters of HT technology from non-adopters. An assessment of data from Manitoba Crop Insurance indicates that producers who have been enrolled in crop insurance for between eleven and thirty years and who farm in the more productive *I* or *J* soil zones of Manitoba are more likely to adopt HT canola. Those producers who adopt are also more likely to have a lower canola productivity index than non-HT canola producers, and will likely insure their crops for between 50 and 70 per cent coverage.

Chapter 3 reviews literature regarding adoption and diffusion of new technologies. Mansfield (1961) suggested adoption occurred as a result of imitation, under the assumption that producers are homogeneous. David (1979) and others suggested that there is a threshold at any point in time which will determine if an individual will adopt or not adopt a technology. The threshold is determined by assuming that producers are heterogeneous, and that they adopt new technology at the correct time to maximize their objective function, given their particular mix of characteristics.

Heiman *et al.* (2000) suggest that the imitation model may, in fact, be an impetus of adoption to occur, and prompts diffusion of the technology to occur as more producers observe others with the technology. Ghadim and Pannell (1999) extend this discussion by further suggesting that learning by doing and changing producer perception of technology as a result of learning will further induce diffusion of an innovation.

Traditionally, studies estimating the returns to canola research were conducted in a setting where the research effort was conducted in a public environment. Subsequently, the technologies derived through these means were supplied competitively to the producer. Works by Nagy and Furtan (1978), Ulrich *et al.* (1984) and Ulrich and Furtan (1985) were the first to assess the impact of returns to canola breeding. These studies found that producers stood to gain between sixty-five and seventy per cent of the approximately fifty per cent rate of return made on public canola breeding.

Fulton (1997) and Moschini and Lapan (1997) discuss how the introduction of intellectual property rights has the ability to create oligopolistic industries which provide technologies at non-competitive prices – exactly what has happened with the patenting of canola genes made resistant to particular chemicals. Moschini and Lapan (1997) develop a model which accounts for the change in technology distribution from public to private sectors; specifically, the model shows how the analysis of benefits from the introduction of an innovation changes under a scenario where the innovation is supplied by an imperfectly competitive market.

Moschini *et al.* (2000), Falck-Zepeda *et al.* (2000*a*) and Falck-Zepeda *et al.* (2000*b*) apply the framework developed by Moschini and Lapan (1997) to assess the benefits accruing to producers from adopting Roundup Ready soybeans and Bt cotton in the United States. Each of the studies found that the welfare of domestic US producers increased due to the introduction and adoption of the technologies.

Based on an assessment of data in Chapter 2 which shows the incomplete adoption of HT technology in Manitoba, a model is developed in Chapter 4 which considers adoption of a new technology as a function of the characteristics of the adopters. The model is developed from previous works conducted on the adoption of new innovations by Mansfield (1961), David (1975) and Heiman *et al.* (2000), as well as the conceptual model suggested by Fulton and Keyowski (1999). The model developed in Chapter 4 extends the deterministic nature of the Fulton and Keyowski (1999) model to one that considers the probability of adoption.

The conceptual framework developed in Chapter 4 is applied to the adoption of HT canola in Manitoba in Chapter 5. The empirical model is a two-fold estimation. The first stage estimates the expected yields of different canola varieties; these are then used to determine whether producers realize a benefit from the adoption of HT varieties. The second stage considers different attributes of producers – such as risk aversion, management ability and productivity – along with expected yields over time to determine the probability that producers will adopt the technology. The results show that (1) certain varieties can be shown to give producers higher returns; (2) the probability of adopting HT canola diminishes over time, and (3) differentiating characteristics of producers are key in determining the likelihood of adoption of HT canola.

6.2 Implications of this Study

There are several implications to be drawn from this study. First, the amount that producers benefit from the adoption of HT canola is dependent on the price of the technology. Since HT canola is typically supplied non-competitively, input suppliers have the ability to price new technologies such that the cost saving benefit is offset to some degree.

Second, adoption of HT canola is not only dependent on the price of the respective technologies, but also on the heterogeneous nature of producers. Producers within specific spectrums of attributes consisting of location, risk aversion and management ability are more likely to adopt the technology than those who do not have the same set of characteristics.

6.3 Limitations of this Study

There are several limitations to this thesis. First, the inability to calculate the standard errors due to time constraints does not allow the calculated marginal effects of the logit model to be tested statistically. A key element of future research should be the calculation of the standard errors, which will allow a determination of the statistical significance of the results reported in Chapter 5.

Second, exogenous variables such as weather and type of tillage system employed, and endogenous variables such as fertilizing intensity were omitted from the model estimating expected canola yields. The omission of any of these variables may have caused bias in the results, as each is an important factor in an individual producer's decision to adopt a new technology.

Third, the most recent data utilized in this thesis represents the 2000 crop year. Data are available up to and including the 2003 crop year. Since this thesis considers the adoption of HT technology in canola from the beginning, the additional three years of data which are not incorporated in this analysis would provide a more full representation of the adoption process.

Last, the thesis does not consider either field trial information on new varieties or the timing of varieties becoming available for commercial use. These factors may influence the adoption decision. For example, how many producers adopt a new variety in the first year it is available? How do field trial yields affect a producer's decision to adopt the variety when it first becomes available and in subsequent years? The incorporation of field trial data and timing of variety adoption information into the model of adoption are important topics for future work.

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APPENDIX

2002 Registered Conventional Canola Varieties

41P55
44A89
45A02
46A05
46A40
46A65
AC Parkland
AC Sunshine
AC-H102
Agassiz
Allons
Apollo
B2416
Battleford
Beacon
Bounty
Bullet
Cash
Castor
Celebra
Chinook
Clavet
Colt
Coronet
Crusher
Cyclone
Defender
Delta
DMS 100
Dynamite
Eagle
Ebony
Eldorado
Elect
Excel
Fairview
Frontier
Garrison
Global
Goldrush
Goliath
HCN 28
HL99
Holly
Horizon
Hudson
Hylite
Hyola
Hyola 401
Hyola 402
Hyola 420
Hypertar
Hysyn 110
Hysyn 111
Hysyn 120 CS
IMC 02
IMC 03
IMC 105
IMC140
Impact
Impulse
Jewel
Klondike
LA 161
LA 269
Legacy
Legend
LG 3220
LG 3310
Magnum
Maverick
Mercury
Millenium
Minot
Neptune
NEX 500
Norseman
Optimum
Pearl
Princeton
Profit
Promark 220
Q 2
Quantum
Reward
Springfield
Sprint
Tobin
Tristar
Valleyview
Vanguard
Westar
Westwin
WILDCAT

2002 Registered Herbicide Tolerant Canola Varieties

2473
2631LL
45A50
45A51
45A71
46A72
46A73
46A74
46A76
Exceed
Hysyn 101 RR
Independence
Innovator
Invigor 2063
Invigor 2153
Invigor 2163
Invigor 2273
Invigor 2473
LG 3235
LG 3295
LG 3345
LG 3360
LG 3369
LG 3930
LG DAWN
PGS 3850
PGS 3880
Polo
Quest
Seville
Stallion
SW Arrow
SW Rider
Trojan