Breeders’ Rights and Open Source Crop Germplasm

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Abstract

The freedom to operate (FTO) and the costs of acquiring and protecting intellectual property (IP) has become a major concern among both private and public plant breeders, especially in the IP intensive transgenic crops. Despite the developments in biotechnology, crop breeding still remains a sequential process where the best new varieties build on the successful varieties of the past. Given this breeding process, if FTO reduces the ability of breeders to access the best germplasm this could slow the rate of global crop improvement in both transgenic and non-transgenic crops. This potential problem has led many agricultural science leaders to raise concern about the possibility of an anti-commons developing because of growing freedom to operate issues.

One of the solutions that is proposed for the growing FTO issue in plant breeding is the development of "open source" research platforms similar to those that led to the development of the Linux computer operating system. With an open source research process anyone is able to use the research platform to develop commercial products but any improvements made to the research platform become part of the platform for future users. The proponents of this approach, such as CAMBIA, argue that it will maintain access to critical intellectual property and allow optimal sharing of knowledge to take place.

In this paper we examine the intellectual property rights associated with crop germplasm and varieties in Canada. We show that the "breeder rights" that are built into many current systems of breeder rights systems create a *de facto* open source system. This system allows breeders to use previously released varieties as breeding material for their own breeding programs allowing them to improve their own germplasm base. Once this is done, and a new variety is released from the program, it then becomes available for other breeders to use in the same manner. Few would argue that this system has not had a long history of success.

As a counterfactual we consider the case where provisions of the UPOV 1991 act are used to give plant breeders the rights to not only protect their current varieties from being illegally copied but would also give them claim over any future varieties developed that use their variety as breeding material. In the factual, a three stage model has two public sector breeders seeking to maximize the benefits of their varieties over a heterogeneous group of

farmers. In the first stage of the model the breeders decide the optimum amount of germplasm to share between each other. The second stage of the model requires the breeders to decide the optimal level of yield it should set as a plant breeding target. In the final stage farmers make an adoption choice basing their decision on the variety that best suits their farm. Backward induction is then used to solve both of the models.

Applying the results of this simulation to the wheat plant breeding system in western Canada, shows that such a revised breeders' rights system would quickly lead to a large number of potential owners for each variety released, which would then increase transactions costs and eventually lead to an anti-commons or FTO issue. In the case where there are no intellectual property rights on varieties breeders are able to produce a variety that more farmers will adopt because breeders' costs will be lower due to germplasm sharing. Once intellectual property rights are introduced into the system, breeders choose to reduce the amount of variety sharing, which then reduces the number of farmers who would adopt the new variety, thus decreasing the benefits for farmers. Given this outcome, jurisdictions that implement the provisions of UPOV 1991 which may hinder FTO, may find benefits from developing other legal measures to maintain an open source type access to germplasm.

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Table of Contents

Permission to Use i
Abstract ii
Acknowledgements iv
Table of Contents v
List of Tables vii
List of Figures viii
1 Introduction to Thesis 1
1.1 Objective 2
1.2 Hypothesis 3
1.3 Thesis Overview 3
2 Literature Review 5
2.1 Fundamentals of Plant Breeding 6
2.1.1 Incremental Nature of Plant Breeding 8
2.2 Is There Freedom To Operate in Plant Breeding? 9
2.3 Strategies Germplasm Institutions use to mitigate FTO 16
2.3.1 Strategies Used Under the Current System 16
2.3.2 Changes Proposed to System 19
2.4 Conclusion 20
3 Shared Germplasm 22
3.1 Introduction 22
3.2 Software Development 23
3.3 Plant Variety Development in Canada 25
3.3.1 Open Source Preservation of Genetic Variation 25
3.4 UPOV 1991 28
3.4.1 Principle of Essential Derivation and Dual Protection 29
3.5 Conclusion 33
4 Theoretical Model 34
4.1 Introduction 34
4.2 Model Description 36
4.2.1 Farmers Demand for Varieties 36
4.2.2 Breeders' Decision on Yield Output 39

4.2.3 Breeders' Decision on level of variety sharing 44
4.3 Baseline Values for the Model 45
4.4 Comparative Statics 45
4.5 Conclusion and Policy Implications 50
5 Pedigree Analysis 51
5.1 Introduction 52
5.2 Methodology used for Pedigree Analysis 54
5.2.1 Key Dates in Variety Development 55
5.2.2 Data Sources 58
5.2.3 Breeding Line Composition Analysis 59
5.2.4 Origins of Germplasm Analysis 60
5.3 Results and Discussion 62
5.3.1 Breeding Line Composition 63
5.3.2 Origins of Germplasm 66
5.4 Freedom-to-Operate Analysis 72
5.5 Conclusion 74
6 Concluding Remarks 76
6.1 Summary 76
6.2 Conclusion 77
6.3 Study Limitations 79
6.4 Study Extensions 80
7 References 81

List of Tables

Table 1 - Comparison between open source software and "open source" germplasm 27

Table 2 - Paremeter Values Used in Simulations 45

Table 3 - Comparative Static Analysis of the Breeders' Sharing Objective Function 46

Table 4 - Distribution of Acreage Devoted to Specific CWRS varieties in Western Canada. (G=Publicly Bred, P = Privately Bred, U = University Bred 53

Table 5 - Composition of Breeding Lines in AAFC Bred CWRS wheat Varieties.......... 64

Table 6 - Composition of Breeding Lines in Private Company Bred CWRS wheat Varieties 65

Table 7 - Composition of Breeding Lines in University Bred CWRS wheat Varieties ... 66

Table 8 - Origins of Breeding Lines used in AAFC Bred CWRS Wheat Varieties 69

Table 9 - Origins of Breeding Lines used in Private Company Bred CWRS wheat Varieties 70

Table 10 - Origins of Breeding Lines used in University Bred CWRS wheat varieties... 72

List of Figures

Figure 1 –Estimated Net Present Value of Yield Increasing Wheat Variety Research Output in Canada 1960-1999 (Gray and Malla 2000) 31

Figure 2 - Farmers Differentiated by Land Attribute... 38

Figure 3 - Best Response Functions for yield output according to sharing (δ) level........ 43

Figure 4 - Net Welfare Changes as Transaction Costs Change 47

Figure 5 - Timeline for Variety Protection 56

Figure 6 - Decision Tree used for assigning registration status to breeding lines 60

Figure 7 - Decision tree used for assigning breeding line ownership............................... 62

1 Introduction to Thesis

Plant breeding and crop improvements are essential components of the crop production supply chain. Ongoing research into crop improvement is needed to increase yields, introduce new traits and technologies, and to keep up with the constant evolution of crop pests. Worldwide there are many different crops grown for different end uses and objectives, but they can be broadly categorized either as being sold for profit or grown for subsistence use.

The structure of the plant breeding activities varies depending on the attributes of the selected crop and the country it is grown in. As a general rule privately funded plant breeding activities tend to develop in countries or crops that have a mechanism that allow for the recurring sale of seed. In countries or crops which lack mechanisms to enable the recurring sale of seed publicly funded or farmer funded plant breeding activities tend to develop. Also in some crops farmer self selection breeding activities occur. It is important to note that whether it is a public, private, or farmer breeder developing a new variety the success of the breeding program will depend on the access to genetic variation

The world's supply of genetic variation via its stable of genetic resources is finite. There are only two methods that a breeder can use to introduce non-transgenic genetic variation into a plant breeding program. One method is to use chemicals or radiation to induce mutations into a breeding line, the other method is to use germplasm from other breeders' programs or landrace species. If the pedigrees of released varieties are analyzed, it is apparent that the vast majority of them have been developed using crosses from external sources of variation.

The importance of plant breeders being able to access these finite genetic resources is paramount for the development of new plant varieties. Plant breeders, both public and private, need to be able to share germplasm amongst them as freely as possible to sustain the crop production system. Without the critical input of germplasm the output of crop improvement becomes difficult. There appears to be a trend towards plant developers wanting ownership of varieties and germplasm that they have developed. This is resulting in a fragmented plant breeding industry in some crops that is having unintended consequences. This thesis looks at the unintended consequences of strengthening intellectual property mechanisms available to plant breeders.

1.1 Objective

The objective of this thesis is to explore the effects and extent that sharing of germplasm has benefited public wheat breeders and the farmers that grow the varieties in Canada. From this baseline we intend to determine how the public wheat breeding system in Canada will be affected if stronger plant breeder's rights are implemented and breeders choose to use them. It is important to differentiate between strengthened breeders rights regarding farmers ability to save seed and strengthened breeders rights regarding plant breeders ability to access germplasm. Breeder's rights that are designed to prevent farmers from saving seed will have a different effect on plant breeders than those that are designed to characterize the ownership of germplasm. In this thesis stronger breeders rights that provide a mechanism for ownership are examined for how they affect a wheat breeder's ability to access genetic variation and produce more suitable varieties, and subsequently wheat farmers' welfare from using a new variety. This research will be beneficial and useful as an aid for making policy decisions that may unintentionally affect wheat breeder's ability to generate economically and socially desirable germplasm improvements.

The purpose of this thesis is to not outright prove or disprove the impact that stronger breeder's rights will have on future plant breeding efforts. Rather we strive to provide theoretical and empirical evidence to support the hypotheses put forward in the next section. There will not be a formal statistical test for the hypotheses, instead there is a discussion about them in the final chapter which brings together all of the evidence laid out in this thesis.

1.2 Hypothesis

H1 **–** Restrictions or policies that affect public wheat breeders' costs to access new genetic variation through sharing of germplasm with other wheat breeders will result in fewer varieties being developed, slower germplasm improvement and a subsequent loss of wheat farmer's welfare.

H2-With the adoption of UPOV 1991 the historic patterns of sequential breeding would result in many potential owners of breeding lines creating freedom-to-operate issues.

1.3 Thesis Overview

The rest of the thesis that follows is divided into 5 interrelated chapters. Chapter 2 offers a literature review that explores the basics of plant breeding techniques and defines the incremental nature of the practice. It then discusses the Freedom-to-Operate problem and how organizations are currently dealing with it and how they could deal with it in the future. Chapter 3 is used to explore the parallels between wheat breeding in

Canada and Open Source computer software and to discuss the possible implications of the proposed amendments to the Plant Breeder's Rights Act (PBRA). Chapter 4 presents an analytical model that can be used to show the negative effects of increased costs of plant breeder germplasm sharing under the proposed changes to the PBRA. Chapter 5 is an empirical chapter presenting pedigree analysis of registered CWRS varieties in Canada which is used to access the potential for FTO problems. Chapter 6 concludes the thesis.

2 Literature Review

This literature review covers several basic concepts relevant to plant breeding. Information about various plant breeding techniques and the components of a typical breeding program are discussed. The concept that genetic diversity is a finite resource and that any improvements through plant breeding are incremental is explored. Legal excludability mechanisms differ throughout most countries in the world; the mechanisms that are available in Canada are then discussed. The final discussion explores the Freedom-to-Operate (FTO) literature and what has been proposed to decrease the problem.

Section 2.1 includes an overview on the fundamentals of plant breeding highlighting the differences between transgenic and non-transgenic breeding techniques. Section 2.1.1 then contrasts novel and incremental plant breeding innovations, and focuses on the fact that plant breeding by nature is an almost entirely incremental field of research. Section 2.2 is used to show the types of Intellectual Property (IP) protection used by Canadian plant breeding organizations and how they affect subsequent research. The section begins with an explanation of the types of legal and biological excludability built into plant breeding research. Legal excludability is focused on and expanded to show how patents/farmer contracts and Plant Breeders' Rights (PBR's) are used to protect plant breeding investments from free riders. Then it is shown how these legal excludability mechanisms can affect subsequent research through a reduction in freedom to operate in both perfect and imperfect patent information scenarios.

In Section 2.3 the strategies used to ensure freedom to operate in plant breeding are discussed. This section is broken down into two sub-sections; sub-section 2.3.1 shows how firms can attempt to secure freedom to operate under the current IP situation using patent searches, building patent portfolios, and inventing around key technologies. In sub-section 2.3.2, it is shown how changes to the system which include patent buyouts, increasing the patentability standards for an invention, and finally how a collectivization of IP could all be used in different circumstances to increase industry FTO.

2.1 Fundamentals of Plant Breeding

Seed genetics have been altered by humans beginning with the domestication of landrace species. These early plant breeders' were actually farmers who were unconsciously selecting seeds with characteristics that were beneficial for them. For example, seeds that did not fall to the ground at maturity could be harvested easier, seeds that lacked dormancy would grow the next year, and plants that produced more palatable edible parts would be used more often. Plant breeder N.I. Vavilov asserts these early improvements and all subsequent improvements can be thought of simply as "evolution directed by the will of man." This desirable and unconscious crop improvement carried on for thousands of years until an understanding of genetics and statistical methods allowed for more specialized crop enhancements.

Modern plant breeding methods can be divided into transgenic and non-transgenic breeding methods. In a broad sense these two methods both seek to combine and utilize genetic variation to produce a new variety. The difference is that transgenic varieties use interspecies genetic variation and non-transgenic varieties rely on intraspecies genetic variation.

Conventional (non-transgenic) plant breeding in its simplest form uses Mendelian genetic principles to predict the inheritance of traits in plants. Essentially crosses are made between genetically different plants with desirable characteristics and then the offspring are consciously selected on the basis of what the breeder would like to improve. The genetically diverse plants used in creating these crosses are obtained either from sharing germplasm with other breeding programs, from landrace species, or it is obtained using mutagenesis techniques. These improvements typically involve complex quantitative traits such as improved yields and quality (Asins 2002) or simpler qualitative traits such as lodging or some types of disease resistance (Sparnaaij and Bos 1993).

As knowledge increased about the functions of plant genetics, more sophisticated plant breeding methods began to arise. Scientists began to use techniques such as *Agrobacterium* mediated (Herrera-Estrella et al 1983) and biolistic-mediated (Klein et al. 1987) gene transferring mechanisms which allowed for interspecies genetic sequences to be inserted into plant varieties. These improved methods allowed for the introduction of traits foreign to their host plants as well as quicker and more efficient breeding of qualitative traits that can be controlled by altering a single gene. At present, these sophisticated breeding methods have been limited to altering qualitative traits of a plant. However ongoing work into integrating “disciplines such as structural genomics, transcriptomics, proteomics and metabolomics with plant physiology and plant breeding” as well as the understanding of the function of heterosis in plants may allow for breakthroughs in the alteration of quantitative traits such as yield (Varshney et al. 2005, pg 628).

2.1.1 Incremental Nature of Plant Breeding

All innovations can be generally considered either novel or incremental by their nature (Noteboom 1999). Innovations that improve on a previous advancement along a particular technology innovation trajectory are considered incremental. Conversely, innovations that create an entirely new platform for research or a new product are considered novel.

These two types of innovations can then be linked to firm characteristics which practice these particular types of innovation. Henderson (1993) shows that incumbent firms are more likely to undertake research in incremental innovations, while entering firms are more likely to undertake research in novel innovations. This relationship seems to hold true in the plant breeding industry in Canada when we substitute private companies for incumbent firms and publicly funded institutions for entering firms in the example. Thus, most novel innovations have tended to come from public institutions in the past because of their public good nature and their low probability for success (Malla and Gray 2005).

Using this framework one can fit innovations resulting from plant breeding research into both categories, depending on the nature of research. In the development of an entirely new crop such as canola the plant breeding research is considered novel. The varieties of rapeseed that were converted to low erucic and glucosinolate varieties of canola were a departure from the typical breeding efforts of rapeseed (Stefansson and

Downey 1995). On the other hand, the breeding of a crop for higher yields can be considered incremental. Beyond the fact that plant breeding fosters both novel and incremental type innovations, most plant breeding innovations are, in practice, considered incremental (Bijman and Joly 2001). Generally the genetics in one newly released cultivar are used to create other cultivars, thus research advances often build upon previous advances. This incremental nature of plant breeding creates some serious implications for future research when excludability is introduced to the system via stronger intellectual property rights.

2.2 Is There Freedom To Operate in Plant Breeding?

Knowledge innovation has the unique characteristic that it is easily imitated or copied. Thus, in order to encourage innovations from organizations seeking profit there has to be a way for them to protect their knowledge innovations from free riders. Intellectual property (IP) legal protection is one way of protecting this type of innovation. When a new process or product is created a patent, trademark or copyright is applied to it, preventing use of the innovation without permission of the holder of the patent, trademark, or copyright. In effect, the IP holder is granted the right to prohibit others from using their idea. Also, if the idea is commercialized the protection grants the patent holder a monopoly over the market of the new invention for a period of time. The monopoly status is designed to allow the inventor sufficient time to recoup the costs of research and receive a return on investment.

In the past agricultural research innovation, in particular, was non-rival and non-excludable, hence a public good. The public good was available to everyone and freely shared between researchers in Canada and worldwide. The only methods available to organizations that allowed them to exclude others from their research were the production of hybrid crops. The seed from hybrid crops could not be replanted without suffering genetic losses, and the inbred parent lines used to produce the hybrids were kept secret. More recently, increased sophistication in plant breeding methods via biotechnology have resulted in a need for legal excludability to be adapted to some types of agricultural research output (Phillips 2000). It has been argued in the literature that in order for for-profit innovation to occur the innovator must be guaranteed a way to exclude others from free riding on the invention (Wright 1983). This concept of excluding others from knowledge to increase research has led to the current legal framework that we have developed to protect private plant breeding initiatives. This change in research output from non-excludable to excludable changes the nature of the good from a public good to a toll good.

In Canada there are three common methods in which plant breeding organizations can legally protect themselves from others free riding on their work. In this instance the groups that could possibly be free riders on research include farmers saving seed and rival organizations copying technology. First, an organization can apply for a utility patent on traits and processes which protects them from both groups of potential free riders. Second, the breeding organization can apply for Plant Breeders' Rights (PBR) protection which partially protects them from rival organizations. To a lesser extent there is also trade secret protection on some inbred lines used for the production of hybrids. These three methods can be combined in different permutations to provide a level of protection for organizations.

There are also two other methods not based on legal protection used by plant breeding organizations to protect their work from farmers free-riding on their seed investments. Hybrid varieties can not be grown successfully in subsequent years, thus farmers must buy seed every year. Also some companies choose to allow farmers to grow and save seed of a particular variety and then try to recoup their seed investment through chemical sales[1]. These methods seem to be effective in some cases and can be less expensive than seeking legal protection making, them attractive to private organizations. Although, not all crops lend themselves to easy commercial hybridization. Self-pollinated crops such as wheat and barley are more difficult to produce hybrids with on a commercial scale than cross-pollinated crops such as canola and corn.

The practice of using utility patents to protect traits and processes in living organisms in Canada began in 1982 when Abitibi Co. sought a patent for a yeast culture and Connaught Laboratories sought a patent for a cell line (Kuyek 2004). Canada's Patent Act does not explicitly outline what living organisms (besides humans) can and can not be patented. This grey area has been both muddied further and cleared up partially by a series of court decisions. The uncertainty surrounding living organism patents was partially clarified by the Supreme Court of Canada's (SCC) closely contested decisions on two landmark cases. In *Commissioner of Patents vs. Presidents and Fellows of Harvard College* it was decided that patents on higher life forms are not allowed. This

[1] This method is being used by BASF for some of their Clearfield traits in lentils, wheat and canola. Farmers can save the seed from these crops, however they must buy a proprietary herbicide if they wish to utilize the technology.

decision drew a line between higher and lower life forms, but not a clear division. It also raised concerns about the validity of plant patents that were partially reconciled in the case of *Monsanto Canada Inc. vs. Schmeiser,* which decided that a patent on a specific gene or part of a plant could provide protection of the plant in general (Lepage-Monette 2004). Nevertheless, the use of utility patents in Canadian plant breeding is a very strong method of guaranteeing excludability.

Further to the discussion about patent protection is an important difference between the U.S. and Canadian patent legislation. In the U.S. a first-to-invent rule is used to determine the rightful patent owner should a dispute arise. Comparatively, a first-to-file rule is used to determine the patent owner in Canada (Lemley and Shapiro 2005). This difference has a drastic influence on the incentives that innovators have to disclose their inventions to the public. The Canadian system encourages rapid and sometimes even premature disclosure of a particular innovation, while the American system seems to encourage innovators to wait until the last possible moment to disclose their innovation (Ordover 1991).

An extension of patent rights in the form of farmer-plant breeding organization contracts are used to inform farmers that reusing seed that contains patented traits will result in infringing on their patent. Interestingly, these contracts can be either implicit or explicit. In the case of Monsanto's Roundup Ready technology farmers have to sign an agreement not to use or distribute the second generation seed. However, farmers using Bayer CropScience's Liberty Link proprietary technology do not have to sign an agreement before purchase. Instead the agreement to not replant the seed is implied when the bag is purchased, and opening the bag implies knowledge that a patent will be infringed upon if the seed is reused (i.e. it is a Shrink Wrap type Agreement).

Secondary to utility patents, PBRs in Canada play a relatively minor role in protecting research output. Under the current regulations based on the agreement reached at UPOV 1978, all that PBR's protect Canadian plant breeding organizations from is others copying and selling their unique registered variety. The rights granted do not prevent other plant breeding programs from using the protected variety to create different varieties, nor does it prevent farmers from reusing their home-grown seed. However, the strength of this type of protection could increase changed drastically if the amendments proposed in UPOV 1991 act were used instead of the 1978 act. This is an important point that will be elaborated upon further in Section 3.4.1.

Because of their limited nature PBRs will have less of an impact on a plant breeding institutions freedom-to-operate than a utility patent (Binenbaum 2003). Freedom-to-operate is defined as

> "The ability to undertake research, development, and sales involving a particular technology while minimizing risk of infringing unlicensed property of others."(Egelyng 2005 pg. 10).

PBRs under their current scope can not be used to limit the dispersion of a proprietary variety in any competing company's research program, whereas a utility patent can. This fundamental difference results in PBRs having an almost negligible effect on non-transgenic plant breeding FTO in Canada.

However, the freedom to operate problem could contribute to the lack of development of new transgenic plant varieties in two ways. If there is imperfect information about the IP landscape surrounding a particular invention then the presence of a submarine patent could result in a hold up problem which might prevent research in a specific area from ever taking place (Stovin and Phillips 2000). However, even if there is a complete understanding of the IP landscape surrounding the innovation the diverse patent thicket may increase the difficulty or even prevent technologies or traits from being combined in a new variety (Sehgal 1996). It is clear that the presence of patents in the plant breeding industry have the potential to hamper freedom to operate, whether or not they are known.

In the creation of a new biotech variety the organization may inadvertently infringe upon an existing unknown patent, potentially causing a hold-up problem. In this scenario when the variety is set to be commercialized the owner of the infringed patent will have an incentive to approach the infringer and seek licensing rents. Even if the patent owner realized an infringement was occurring on a patent it would be in the best interest of the patent holder to wait until the variety was commercialized, as the sunk costs incurred by the infringer would result in a bargaining advantage for the patent owner. With this knowledge in hand that any patent infringement would not show up until the commercialization stage of development, there is a strong incentive for the organization not to invest in the first place.

The other scenario where the freedom to operate problem may reduce downstream innovations is in the combination of traits –both transgenic and non-transgenic under UPOV 1991. As biotechnology progresses and consumers become more comfortable with the technology there will be a strong will to combine both input traits (disease, insect and herbicide tolerance) with output traits (nutrition profiles, and processing benefits) to create a better variety for all stakeholders in the agricultural crops supply chain. The diverse ownership spectrum of IP involved in this process may prevent this from happening or make it very onerous to do so (Sehgal 1996). This problem of many owners of IP limiting downstream ownership is not only limited to crops which are able to incorporate biotech type traits. Lesser and Mutschler (2004) show that the relatedness requirements included in the UPOV 1991 act will reduce the level of pre-breeding activities and the incorporation of beneficial traits in new varieties to below the socially optimum level.

The incentives around agricultural research are at a crossroads. On one hand it appears that stronger IP protection is needed to give private organizations an incentive to continue innovating. It is believed that for-profit organizations will only spend money on R&D if they know that they can be protected from free-riders capitalizing on their initial investment. On the other hand the freedom-to-operate problem suggests that weaker IP protection is needed in order to give organizations an incentive to invest in second generation research. This paradox is especially apparent when we have institutions that are publicly funded (i.e. Agriculture and Agri-Food Canada and universities) trying to act as for-profit institutions. Essentially policy makers have to recognize the trade off between both of these two deterrents to research, (ie. the free-rider problem and the freedom-to-operate problem)and develop policies and institutions to manage the dilemma.

2.3 Strategies Germplasm Institutions use to mitigate FTO

This section discusses strategies that can be used to mitigate the freedom-to-operate in research endeavors. A distinction is made between strategies that can be used given the existing IP framework available and changes that could be made or added to the system.

2.3.1 Strategies Used Under the Current System

Plant breeding organizations, both for-profit and non-profit, need to understand and have a strategy for preserving their FTO under the current system. There are three methods that can be used (each with their own limitations) by organizations to create FTO for research. Patent searches allow an organization to recognize the potential IP complications in their field of research. Building up a broad IP portfolio could be used both to bargain for FTO and to stop other organizations from litigating a potential infringement. Finally, if a key blocking patent is identified then research could be used to invent around the piece of IP. These strategies are used to some degree both in conjunction with each other and without.

Prior to partaking research in an area, it is prudent for an organization to conduct a patent search. Knowledge of the patents that could be infringed upon when it is time for commercialization of a new crop variety may allow the research organization to better manage a possible infringement problem (Kimpel 1999). Either the researcher would choose not to do the research, or at least the researcher would know who to negotiate with if the project were to proceed.

Although this method is an important start to any research project, it is still only a second-best solution. First, it is difficult to anticipate all of the patents that may affect the final research product, when it is not precisely known what the final research product will be. For example, Potrkus (2001) shows that the technology used to create a new cultivar of rice rich in vitamin A (Golden Rice) used the genetic traits and techniques from 70 pieces of Intellectual Property (IP). Second, the scope of a patent as interpreted by the courts is open to interpretation, which makes anticipating patent infringement also open to interpretation (Ko 1992). Therefore, even though a researcher may believe that a prior patent is not being infringed upon in the development of a new variety a court could decide otherwise. Another drawback to the prior patent search method has to do with the transparency of ownership of a particular patent (Roa-Rodriguez & Nottenburg 2003). It is common practice for patent owners to never actually utilize their own patents to commercialize products; instead the rights to the patent are licensed out to other firms. Interestingly, it is not required by law for patent owners to disclose who the patent is licensed to. Therefore, even though it is explicitly stated on the patent application who owns the patent, it is not clear who actually controls the patent, thus making it difficult to negotiate. Even with these limitations on patent searches as a method to ensure FTO, it is still a necessary step for researchers to do a patent search.

A second method used by organizations to ensure their FTO is to try to increase the number of patents in their portfolio (Nottenburg et al. 2001). While it seems rather perverse that increasing the amount of patents each organization owns would ensure FTO, it is a strategy used for two reasons. One strategy is to increase your IP portfolio enough so that when it comes time to negotiate for licences, IP is swapped royalty free instead of paying royalties back and forth. A second reason for increasing patenting activities is to increase the chance that there is ownership of a patent that is infringed upon by a rival organization. In this scenario if two or more organizations have a complementary IP portfolio then there is less chance that they will litigate each other out of fear of retaliatory action (Nottenburg et al. 2002). It is important to note that this strategy of building up a patent portfolio will only work for established organizations. It will not be effective for entering organizations and will most likely work against them as the incumbents will use their portfolios in a predatory action.

In the case where a single technology is inhibiting an organization's FTO, it may be beneficial to attempt to invent around a patent. Up until recently there have been only two methods of genetically modifying plants by transferring foreign genes into them. Both methods have a significant patent thicket around them with patents owned by Monsanto, DuPont, and various American universities (Pray and Naseem 2005). Research is currently underway to develop other methods of transferring genes into plants. In fact, Broothearts et al. (2005) show a promising new method of genetic modification that uses a species other than *agrobacterium* to transfer foreign genes into a plant.

Of course, inventing around a key technology would only be beneficial to an industry if the inventor was willing to share the invention. What is unique about Broothearts et al. (2005) invention is that the invention's owner (an Australian organization -CAMBIA) is using an open-source type license on the technology which allows firms who fit their criteria to use it free of charge.

2.3.2 Changes Proposed to System

In order to ensure FTO in the plant breeding industry it has been suggested that governments or regulators could intervene. If a key process patent is holding up innovation in an area, it is possible for government to buy out the patent from the owner and then freely distribute the rights. Also if the patenting requirements of non-obviousness and novelty were tightened it may reduce the number of patents granted. Finally a collective agency may be formed to manage IP produced at non-profit institutions that would ease the friction of multiple patent holders.

If an organization holds a key patent that is restricting the development of the industry, Callan and Cervantes (2001) suggest that the government could buy out the patent. In this situation the government would buy out the patent and place it in the public domain, so that access would be granted to anybody who would want to use the technology. The difficulty with implementing this scenario is to determine the value of the patent both to the inventor and to society in general (Kremer 1998).

A reform of patent standards may reduce the number of superficial patents granted. In order for a patent to be granted for an invention, the invention must have, among other qualities, non-obviousness, novelty, and utility. Barton (2000) argues that the US Patent and Trademark Office (USPTO) does not have stringent enough standards on the non-obviousness and novelty requirements for patents. If the guidelines for non-obviousness were to be strengthened, it would result in fewer numbers of patents being granted. If there were fewer patents created in the first place, then there would likely be less chance for claims that would restrict FTO.

A solution to the problem of negotiating with many different patent holders may lie with the collectivization of IP. An American initiative dubbed the Public Intellectual Property Resource for Agriculture (PIPRA) is suggesting that all IP created at public institutions be pooled and managed as a collective portfolio. The main purpose behind this proposal is to create a very large company that would manage (not control) all IP created at participating public institutions (Atkinson et al. 2003). This would ensure public institutions FTO, as all patents in the particular field of research done by the participating organizations would be catalogued and it would be relatively easy to determine who owns the rights to a technology. This would also prevent public agencies from having access denied for a technology that they originally created.

PIPRA also believes that its organization would benefit private research as well. If all public IP is collectively managed, then the managers of PIPRA could put together patent packages for private firms to use. For example if a private firm had an area they were wanting to research, PIPRA could deliver a list of all of the patents in that subject area. As an extension PIPRA is also working at producing technology platforms with its IP portfolio.

2.4 Conclusion

In this chapter several key points were identified that set the stage for the rest of the thesis. The practices surrounding plant breeding in Canada have changed from simple conventional methods to sophisticated biotech methods for some crops. The sophistication has spurred private research interests and created a very complex legal structure surrounding biotechnology. It is clear from section 2.2 that any future policy directions must weigh the trade-offs between the free rider problem and the freedom to operate problem. Although there are strategies available to firms to ensure FTO in biotech crops, probably the strategies that show the greatest potential will come from non-profit institutions.

3 Shared Germplasm

3.1 Introduction

Computer software development is a relatively new and rapidly evolving industry. In the industry there are many different types of software developers each with unique motivations. Each of these developers fills a particular niche in the market. A similar situation is alsooccurring in the plant breeding industry. In the plant breeding industy there is a mixture of variety developers each with unique motivations.

An interesting parallel can be made between the open source development niche in the software market and the publicly funded wheat variety development niche in the crop variety market. The variety registration regulatory system and the accompanying Plant Breeders' Rights act combine to create a *de facto* open source system. It seems as though the freedom to operate concerns that are driving the expansion of the open source niche in software development are already alleviated in the current wheat plant breeding system.

Proposed amendments to the Plant Breeders' Rights act in Canada may represent a step away from the current freedom to operate level that the current system enjoys. The principle of essential derivation provision of the UPOV 1991 agreement could result in a reduction of freedom to operate, if plant breeders choose to protect their varieties with it.

3.2 Software Development

Computer software development is a widespread industry comprised of a number of developers all with unique incentives. It seems as though most software developers want to create a useful product, however they differ in their motivations as to why they want to produce a useful product. Private software developing companies such as Microsoft tend to produce software for a profit. Individual software developers (such as ones involved in the creation of Linux) tend to produce software for their own use as well as for greater peer recognition (Lerner and Tirole 2002). Still some other companies such as Apple distribute some of their own software for free, because having people use their software allows them to sell a separate service[2].

In order to develop a new software program the programmer must go through a two-stage process. During the initial stage of development the instructions or source code is keyed into the computer using a written language. Computer processors do not understand the written languages used by programmers, so after the source code is completed the written program must be converted to a set of binary numbers which can be read by the computers processor. This two-stage conversion process is a necessary step because it is impossible for programmers to code in binary.

This conversion process is a significant source of protection and excludability for profit motivated software developers. When the source code is converted into binary code it is impossible for others to see how the software is written and make adjustments

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[2] Apple distributes its iTunes software freely to all, which allows it to sell multimedia files through the iTunes service.

or borrow the source code for their own program. Thus, for-profit software creators generally only sell closed source code software – that is software with the binary version of the source code included (Hope 2004).

Selling closed source software may be a benefit for profit motivated developers, but it is an impediment for software users that demand flexibility in their programs. In order for software users to be able to customize their programs they must be able to access the source code. Software programs that come with the binary version and the written version of the source code are known as open source. The concepts of being able to access the source code of a program and make custom modifications plus the fact that when a new software program is introduced it is never complete and can always be improved upon are driving the continued expansion of the open source software movement (Steely 2004).

Open source software is extremely beneficial for those looking for flexibility in their computer software applications. Anyone is allowed to use open source software as a tool to develop new technology provided they follow a set of rules. The rules vary from license to license, but they typically include the following points: "(1) the source code must be available to the user; (2) the software must be redistributable; (3) the software must be modifiable, and the creation of derivative works must be permitted; (4) the license must not discriminate against any user, group of users, or field of endeavor; (5)the license must apply to all parties to whom the software is distributed; (6) the license cannot restrict aggregations of software (Feller and Fitzgerald 2000)."

The software development industry is comprised of both open and closed source software developers. It is apparent that the developers and users of open source software see great value in being able to use and then slightly modify source code to create an application that suits their needs. However, we cannot ignore the contributions that for-profit closed source software manufactures make to the industry. Some people do not have the need or the desire to create or modify software. Having both systems available to software consumers allows choice and provides the right fit for most people.

3.3 Plant Variety Development in Canada

An interesting parallel between the computer software development industry and the wheat variety development industry in Canada can be drawn. We have both profit (private seed companies) and recognition (public institutions) motivated plant breeders producing varieties for farmers. This section develops the analogy between the development industries using open and closed source varieties as a proxy for open and closed source software. Typically the open source type varieties are non-hybrid self-pollinated crops produced at public institutions. Contrasting this is the production of hybrid/transgenic crops typically bred by private companies.

3.3.1 Open Source Preservation of Genetic Variation

The requirements that the merit based variety registration system puts on plant breeders coupled with the current UPOV 1978 based Plant Breeder's Rights act combine to create "open source" wheat varieties in western Canada. Table 1 describes the key points that make a software program "open source" and then compares the points to how wheat varieties are bred, registered, and protected in Canada.

Source code contained in the software requirement for "open source' software is equivalent to the pedigree information requirement for a new plant variety. In order for software to be considered "open source", the source code must be freely available to users. Providing the source code with the program allows the user to modify the work and troubleshoot the existing, and allows the user of the program to determine what makes the program work. Before any public wheat variety is registered in Canada the "source code" or pedigree information is published in a peer reviewed journal. For an example, see DePauw et al. (2004) for a description of the bread wheat variety Lillian. Providing the source code or pedigree information with a software release or wheat variety is analogous.

Other important comparisons can be drawn using the subsequent modifications conditions of the open source license. The core principle of open source is that no entity can restrict the use, modification, or recombination of open source software with other applications. This principle is in direct alignment with two key provisions in the Canadian Plant Breeder's Rights act. The first provision that is similar to open source is the breeder's exemption. Once a variety is registered the variety is available, royalty free, to any other breeder to use in crosses to produce a new variety. The breeder cannot restrict the further use and modification of a variety, no more than a software programmer can restrict the use and modification of the source code that is written. The second provision that is similar to open source is the farmers' exemption. Once a farmer buys certified seed of a variety that is protected by plant breeder's rights, the farmer is free to keep the seed and reuse it the next year.

One difference between open source and plant breeders' rights, however, is the point where the software must be redistributable. This point is in agreement with the breeder's use of an existing variety, but is in disagreement with the farmer's use of an existing variety. Legally, if farmers grow a crop protected by the current PBR Act then they are not allowed to *sell* the seed from that crop to another farmer for seed use. Farmers are allowed to grow and reproduce the protected variety for their own seed use, they are just not allowed to sell seed to another farmer at a common grade or otherwise (Berg and Recksiedler 2005).

Table 1 - Comparison between open source software and "open source" germplasm

Open Source Condition	Software Perspective	Public Breeders' Perspective (UPOV 1978)
The source code must be available to user.	The software distribution must include the original programming language. If not the source code must be made available by free, public internet download.	All publicly bred wheat varieties registered in Canada must provide pedigree information.
The software must be modifiable, and the creation of derivative works must be permitted.	All users are given the right to modify the software or produce derivative works.	Farmers and Breeders' are both users of varieties. Breeders' can freely modify (cross) varieties and new varieties based off of old varieties are allowed royalty free.
The software must be redistributable.	The user of Open Source (OS) software is given full rights to reproduce and redistribute the software, on any medium, to any party, either gratis or for a fee.	Farmers are allowed to reproduce the variety and use it themselves next year. Farmers are not permitted to sell seed to other farmers.

Adapted from Feller and Fitzgerald (2000)[3]

A final point to be made about the "open source" analogy that can be extended beyond the Canadian example is with the standard material transfer agreement (SMTA) proposed by the Convention on Biological Diversity (CBD). The SMTA is designed to promote "open source" access to varieties produced using the breeding material acquired

[3] This table is adapted from a similar table found in Feller and Fitzgerald (2000)

using the SMTA. Breeders use the SMTA to acquire and introduce genetic variation from gene banks or unimproved genetic resources into their breeding program. There are no restrictions placed on the commercialization of varieties which incorporate genetics acquired using a SMTA. However, Article 6, paragraphs 6.7 and 6.8 of the SMTA present a clear difference in royalty payment schemes which are dependent on the use restrictions put on by the developer. If the developer restricts others from using the commercialized variety in their breeding program, then the developer must make mandatory royalty payments to the governing body of the CBD. Conversely, if the developer does not restrict others from using the commercialized variety, then royalty payments are only voluntary. Plant breeders are rewarded when they provide unrestricted access to their varieties, and penalized when they don't.

3.4 UPOV 1991

Current plant breeder's rights legislation in Canada was given Royal Assent on June 19th, 1990. As part of the legislation it was required that the Act is reviewed after 10 years of implementation to assess the impacts it was having on plant breeders. After the review the biggest change recommended by the reviewing committee was to amend the Act so it conforms to UPOV 1991 standards instead of the UPOV 1978 standards being used (CFIA 2005). Of the multitude of differences between UPOV 1991 and UPOV 1978, the two differences that are the focus of this section are the introduction of the principle of Essential Derivation and allowing for dual patenting and PBR protection of a variety.

3.4.1 Principle of Essential Derivation and Dual Protection

The UPOV 1991 agreement was written with the intent of striking a balance between the reality of plant breeding being incremental in nature and the incentives needed to allow breeding companies to invest in breeding. In order to compromise, the agreement incorporates a slightly different breeders' exemption scheme. The agreement grants a breeders' exemption on all protected varieties if they are not given initial variety status. Plant breeders are still allowed to use non-initial varieties in future breeding efforts without having to pay royalties back to the original breeder under the agreement. The only varieties which are use restricted are those that have been granted initial variety status[4].

Once initial variety status has been determined the UPOV act clearly outlines what may be considered a variety essentially derived from the initial variety.

> "Essentially derived varieties may be obtained for example by the selection of a natural or induced mutant, or of a somaclonal variant, the selection of a variant individual from plants of the initial variety, backcrossing, or transformation by genetic engineering."(UPOV 1991 Act Article 14 paragraph 5c)

There are two problems with the new breeders' exemption scheme included with UPOV 1991. First, it is not clear how or what criteria a variety has to meet in order to be

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[4] How a variety is granted initial variety status is elaborated upon further in this section.

granted initial variety status. Initial variety status is granted through litigation between two breeders' after the variety and subsequent varieties are registered. So, breeders' that are using a protected variety may or may not be using an "initial" variety depending on the outcome of a court decision. This uncertainty creates a hold up/ FTO problem similar to the scenario discussed in section 2.2. The second problem is in the type of varieties that would be granted initial variety status. Generally, breeders will want to use the best genetics available in their crosses. They will not choose to use varieties that are second best. Thus, introducing this amendment may restrict the progress of many wheat breeding programs because the varieties most likely to be granted initial variety status are the varieties that every breeder would like to put in the breeding program. The results of Gray and Malla's (2000) research on the net present value of wheat breeding research are presented in Figure 1.

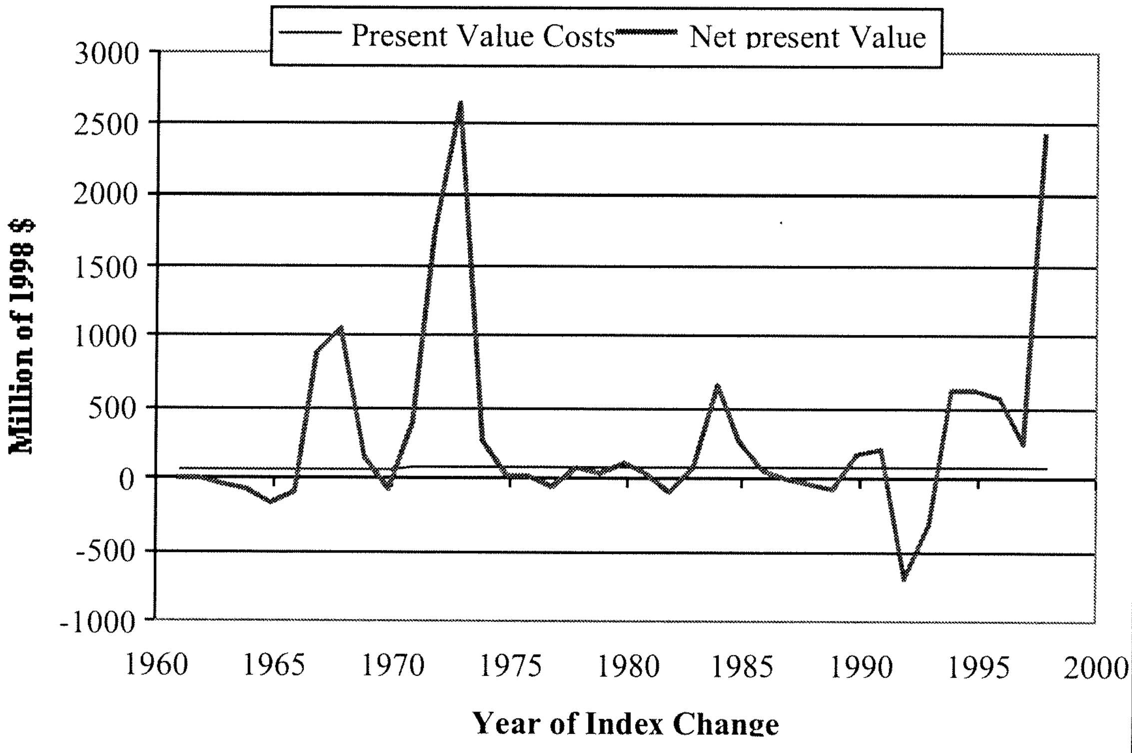

Figure 1 –Estimated Net Present Value of Yield Increasing Wheat Variety Research Output in Canada 1960-1999 (Gray and Malla 2000)

The three spikes upward in the graph around the years 1968, 1972, and 1998 correspond to the adoption of the varieties Neepawa, Katepwa, and AC Barrie. Indeed, after completing pedigree analysis in chapter 5, five of the top six varieties grown on the prairies today can have their genetics traced back to Neepawa.

There are many real examples of plant varieties in Western Canada that have been developed using these types of breeding techniques[5]. The variety CDC Imagine was developed from an induced mutant of the variety CDC Teal (Pozniak and Hucl 2004). AC Corrine was produced using (among other varieties) backcross breeding of the variety

[5] See section 5.4 for a more exhaustive list

Glenlea (Humphreys et al. 2001). There have also been flax varieties that have been derived using somaclonal variants of registered varieties. The flax variety CDC Normandy was developed from a tissue culture of McGregor (Rowland et al. 2001). We can conclude that all of these varieties would have been considered essentially derived from their parent varieties under the UPOV 1991 guidelines, if their parent varieties were considered initial varieties. Whether or not they ever would have been created in the first place had the breeders known that the varieties they were creating would be considered essentially derived is a debatable point.

The second key change being proposed to the Plant Breeders' Rights Act is the potential to have dual protection from both PBR's and patents. While this may be of use or concern when transgenic wheat varieties are introduced, it is not going to have that big of an impact on wheat breeding activities in their current state. Under the patent system in Canada only transgenic genes can be patented.

Boettiger et al. (2004) explore the interaction between plant patents and UPOV 1991 internationally. In their chapter they reference Jordens (2002) who explains that if a holder of a plant patent inserts a gene into a plant variety protected under UPOV 1991 in the U.S. then the holder of the initial variety has complete rights over the newly created variety. In essence, Jordens (2002) shows that UPOV 1991 PBR's trump patent protection in the U.S.A.

Of course the plant breeder or the plant breeding organization has the option of seeking PBR protection on the registered varieties produced. If the breeder/organization did not seek to place PBR protection on the variety none of the concerns outlined would be a problem. This is not that abstract of a concept, as Dr. Brian Fowlers' winter wheat varieties developed at the Crop Development Centre (CDC) are not protected by PBRs. However, he is in the minority as most breeders do utilize the protection provided by PBRs.

3.5 Conclusion

Software and plant variety development are practiced by different entities each with different motivations. Two groups of developers, including publicly funded plant breeders and open source software developers, have common motivations. In fact, the wheat variety development system in Canada is a *de facto* open source system. However, the status of the wheat variety development system continuing to be an "open source" type system is in jeopardy. If proposed amendments to the Plant Breeders' Rights Act are realized, in particular the principle of essential derivation, the wheat variety development system could become crippled and variety development would slow. This is a similar conclusion to that of Falcon and Fowler (2002) who also thought that increased ownership and fragmentation of genetic resources will slow variety development

4 Theoretical Model

Freedom-to-operate by giving and receiving genetic variation between plant breeding organizations is essential for the sustainability of plant breeding activities. Whether the organization is breeding for profit, social welfare or subsistence access to genetic variation and superior combinations of genetics is paramount to the development of new varieties and increases in grain yield and quality (Troyer and Rocheford 2002). In order to assess the impacts of legislative changes that may increase the cost of sharing germplasm between plant breeders, an analytical model is developed in this chapter.

4.1 Introduction

There are many possible interactions and potential sharing partners that plant breeders may face. Organizations such as small and large private seed companies, universities, provincial, state, and federal government agencies, farmer funded breeders, and gene banks all actively work with plants and share germplasm with each other. This flow of genetics is essential for maintaining diversity and maintaining high yielding varieties for the farmers growing the crops. The quest for higher yield varieties applies to all types of breeders no matter what their motivations are. For a private company a high yielding variety will mean greater market share, for a governmental agency a high yielding agency will increase the food supply in the country, and for a subsistence farmer higher yields will mean more food for consumption.

In Canada there are many different types of crops grown. Seeded acreage of major crops grown in 2006 include wheat (26.5M), canola (13.3M), barley(9.5M), oats

(4.7M), field peas (3.5M), soybeans (3.0M), corn (2.7M), flax (2.0M), and lentils (1.4M)[6]. In all of these crops there is a mixture of public and private organizations carrying out variety development work. Typically, public and farmer funded plant breeders are responsible for variety improvements in wheat, barley, oats, field peas, flax, and lentils. Private breeders tend to concentrate on canola, soybeans and corn.

In this section an analytical model is used to examine the sharing incentives that exist between recognition motivated (publicly/farmer funded plant breeders) within the wheat breeding industry. In the model two public sector plant breeders seek to maximize the benefits of their varieties over a heterogeneous group of farmers by determining the amount of germplasm they share with each other. In the first stage of the model the breeders decide the optimum amount of germplasm to share between each other. The second stage of the model requires the breeders to decide the optimal level of yield it should set as a plant breeding target. In the final stage farmers make an adoption choice based on the variety that best suits their farm. The equilibrium sharing, research output and farmer adoption decisions are modeled in three stages. Backward induction is then used to solve the model (Gibbons 1992).

This theoretical model is then used to compare the incentives and equilibrium as it currently exists versus a counterfactual where change occurs that limits the viability of public breeder cooperation and sharing. One example, in particular, that this counterfactual situation could apply to would be the proposed amendments to the Canadian Plant Breeders Rights legislation. If the changes discussed in section 3.4

[6] Data for seeded acreages is available through Statistics Canada

involving UPOV 1991 and the principle of essential derivation are introduced we expect the transfer and sharing of germplasm between plant breeders will become more costly. This increase in transaction costs would come from the uncertainty around which varieties would be considered initial or essentially derived. In order to determine these characteristics for the varieties lawyers and litigation are needed, increasing the costs of creating a new variety.

4.2 Model Description

4.2.1 Farmers Demand for Varieties

In solving the model by backward induction the first stage to be solved is developing the farmer's decision to adopt a specific variety. The analytical techniques in this section are based off previous theoretical work by Malla and Gray (2003). In this study farmers are modeled as a heterogeneous group differentiated by land attributes.

In the model there are n-farmers uniformly distributed and differentiated by their land characteristic Ψ. This differentiating characteristic can be thought of as a difference in soil pH, land location, or fertility. The two varieties available for choice between farmers are horizontally differentiated. Farmers choose to purchase variety A from plant breeder A or variety B from plant breeder B.[7]

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[7] Interestingly, in Canada publicly funded plant breeders never actually sell their varieties to farmers. The sale occurs through a distribution company instead. For simplicity it is assumed that there is a direct sale between farmers and breeders.

All farmers face the same profit maximizing decision which will compare the profits from growing variety A or B (Figure 2). Rational behavior is assumed, so that if profits from variety A are higher than variety B (all farmers between 0 and Ψ*), the farmer will grow variety A. If profits from variety A are less than that of variety B (all farmers between Ψ* and 1), the farmer will grow variety B. If profits are equal between the two varieties for a farmer then the farmer is indifferent between the two varieties. The decision is presented in equation (4.1).

$$Max\Pi_i = p\left[Y_A - \tau\psi_i\right] - w_A + p\left[Y_B - \tau\left(1 - \psi_i\right)\right] - w_B \quad (4.1)$$

Where:

w_A= the seed price of variety A
w_B= the seed price of variety B
p = the output price
Ψ_i = the land characteristic of farmer i
τ = the change in yield associated with a unit change in the differential attribute
Y_A- τ Ψ_i = the yield of variety A for producer characteristic Ψ_i
Y_B- τ $(1- \Psi_i)$ = the yield of variety B for producer characteristic Ψ_i

The yield function specified for each farmer differs slightly from what is commonly found in the literature. Typically the yield function is specified as having a baseline yield (Y_A) and then as the land characteristic increases (Ψ_i) the total yield increases as well (Malla and Gray 2003). The yield function specified in this paper uses a baseline yield (Y_A) and as the land characteristic increases (Ψ_i) the total yield decreases. This is an easier way to understand the problem as it is a more accurate portrayal of a typical farming environment. Under optimal conditions a variety will have a high yield, and as weather, fertility, pests, and other practices effect the crop the yield will decrease from the optimum.

Of course, the two specifications are mathematically indifferent. If the (-) was replaced with a (+) variety A would have its optimal yield on the right side of Figure 2 and have a downward sloping right to left profit function. Variety A would then have its optimal yield on the left side of Figure 2 and have a downward sloping left to right profit function.

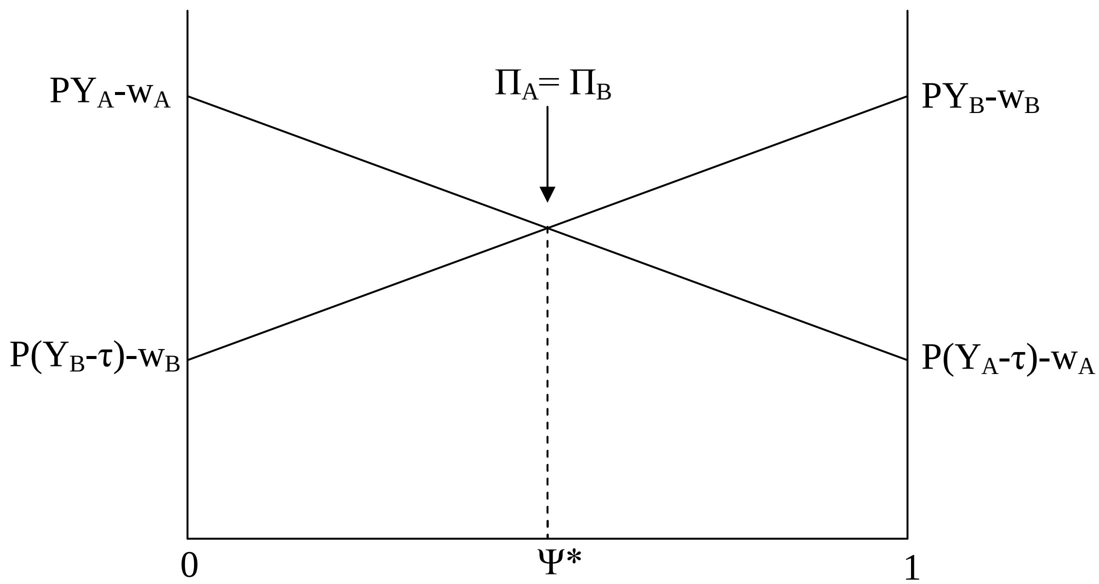

Figure 2 - Farmers Differentiated by Land Attribute

To determine overall market share for the two varieties we use the point Ψ*. The market shares for varieties A and B are shown in equations (4.2) and (4.3) respectively. Importantly, both shares are increasing functions of their own yield and competitors price, and decreasing functions of the competitor yield and own price. The market shares presented can be considered equivalent to the demands for each individual variety.

$$A = \psi^* = \frac{p(Y_A - Y_B) - (w_A - w_B) + p\tau}{2p\tau} \quad (4.2)$$

$$B = 1 - \psi^* = \frac{p\tau - p(Y_A - Y_B) - (w_B - w_A)}{2p\tau} \quad (4.3)$$

4.2.2 Breeders' Decision on Yield Output

In the second stage of the model two plant breeders seek to optimize the level of research output in the form of yield (Y_j) that will maximize benefits for farmers subject to their costs of producing a new variety. This model shows the effects of publicly funded plant breeders which may or may not be funded in part by farmer commodity groups, so the assumption that breeders would like to maximize benefits for farmers instead of their own profits is not that implausible. The Crop Development Centre (CDC) in Saskatoon is partially funded through a wheat check-off administered by the Western Grains Research Foundation and a pulse crop check-off administered by the Saskatchewan Pulse Growers (SPG). Depending on the year, the producers that fund these two groups contribute anywhere from 20-25% of the annual budget[8]. Also, according to winter wheat breeder Dr. Brian Fowler developing a variety that farmers will adopt is important for the success of a variety[9].

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[8] Personal Communications with Marlene Freeman, Manager of Operations/Finance for the CDC.

[9] Personal Communications with Dr. Brian Fowler, Winter Wheat breeder for the CDC

Total farmer benefit from the two varieties is calculated using Figure 2 as an illustration. The farmer benefits from variety A are measured as the area bounded from 0, PY_A-w_A, $\Pi_A=\Pi_B$, and Ψ^*. Accordingly, the farmers benefits from variety B can be measured as the area bounded from 0, PY_B-w_B, $\Pi_A=\Pi_B$, and Ψ^*. Solving for the area of these two trapezoids yields equation (4.4) for farmers growing variety A and equation (4.5) for farmers growing variety B. Importantly, the benefits that farmers receive from growing either variety A or variety B are increasing functions of their own yield and output price, and decreasing functions of their respective seed costs.

$$TB_A = P\psi^* Y_A - \frac{\psi^{*2}\tau P}{2} - \psi^* w_A \tag{4.4}$$

$$TB_B = P(1-\psi^*)Y_B - \frac{(1-\psi^*)^2\tau P}{2} - (1-\psi^*)w_B \tag{4.5}$$

In the game both of the plant breeders are publicly funded breeders without market power, so their varieties will be sold at marginal cost. In order to simplify the model the marginal cost is set equal between the varieties and is equal to 0 ($w_A=w_B=0$). This is not an entirely unrealistic assumption given the non rival/non excludable nature of the public variety good. Wright and Pardey (2006) discuss that over time public varieties have typically been made available at minimal cost to producers. They suggest that farmers' ability to save seed allows for royalties to be collected on the initial seed sale only. Over time this initial royalty becomes finite and approaches zero.

A simple quadratic cost function for each plant breeder is specified to include the desired variables. An analysis of the terms in the cost functions presented in equations (4.6) and (4.7) is presented here. Similar to Poyago-Theotoky (1998) and D'Aspremont and Jacquemin (1988) the quadratic function on the output variable allows the cost function to be well behaved and exhibit decreasing marginal returns to research effort (Y_i^2).

The parameter δ can be interpreted in a number of ways. It can be used to indicate the amount of germplasm that is shared between the breeders, the sharing of research tools and personnel, or simply the level of co-operation used in conducting multi-site breeding line comparisons. Most importantly though it should be interpreted as the ability to share in the distribution and preservation of genetic diversity used in breeding programs. In order to capture the effects of this parameter on the marginal cost of producing a variety the δ is included in the term $\delta Y_i Y_j$.

The parameter ϕ is used to indicate the level of transaction costs that breeders incur if sharing or cooperating is impeded in some way by material transfer agreements or intellectual property protection in the form of patents or PBRs. To capture the effects of this parameter in the breeders' marginal cost the term $Y_i \phi\delta$ is used. Taken all together the cost function is increasing in target yield level and transaction costs and decreasing in the level of shared germplasm. Specifying the cost function in an additive format as shown also allows for the breeder to still incur costs if either the sharing parameter (δ) or the transaction cost parameter (ϕ) are 0.

$$TC_A = C(Y_A^2 - \delta Y_A Y_B + Y_A \phi\delta) \tag{4.6}$$

$$TC_B = C(Y_B^2 - \delta Y_A Y_B + Y_B \phi\delta) \tag{4.7}$$

Now that the benefits that farmers receive and the costs that the plant breeders are set to incur in the creation of a new variety are specified, a mathematical objective function can be created. The objective function for both plant breeders are shown in equations (4.8) and(4.9).

$$MaxW_A = P\psi * Y_A - \frac{\psi *^2 \tau P}{2} - C(Y_A^2 - \delta Y_A Y_B + Y_A \phi\delta) \quad (4.8)$$

$$MaxW_B = P(1-\psi*)Y_B - \frac{(1-\psi*)^2 \tau P}{2} - C(Y_B^2 - \delta Y_A Y_B + Y_B \phi\delta) \quad (4.9)$$

Using optimization techniques to maximize both objective functions with respect to the own yield variable provides best response functions for each breeder. The best response function for breeder A is shown in equation (4.10) and the best response function for breeder B is shown in equation (4.11).

The best response functions show that as transaction costs increase the breeders choose to produce a lower yield. However, as the competitor breeder's yield increases the breeder will choose to produce a higher yield, indicating that the two breeders' yields are strategic complements to each other (Figure 3). Interestingly, this result is true only if sharing is large. If δ is a small number then the two breeders' yields become strategic substitutes. This outcome is not unlike the results that Poyago-Theotoky (1995) found when analyzing spillovers in a duopoly setting. She found when spillovers were large then research output was a strategic complement for firms and when spillovers were small then research output was a strategic substitute for the firms. If firms are allowed to utilize each other's research output then they have an incentive to produce more, and if they can not utilize each others research output then they have an incentive to produce less.

$$Y_A = \frac{\tau P - 4\tau\delta C\phi + Y_B(4\tau\delta C - P)}{8\tau C - 3P} \tag{4.10}$$

$$Y_B = \frac{\tau P - 4\tau\delta C\phi + Y_A(4\tau\delta C - P)}{8\tau C - 3P} \tag{4.11}$$

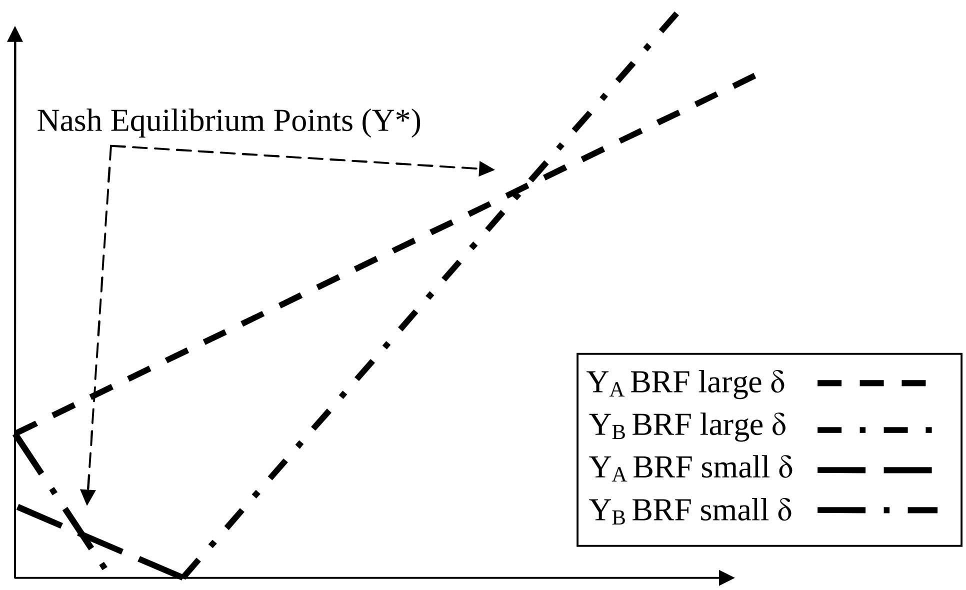

Figure 3 - Best Response Functions for yield output according to sharing (δ) level

At the intersection of the two best response functions for each δ is the Nash Equilibrium solution. Equation (4.12) describes the points indicated in Figure 3. The equation shows that as transaction costs increase then the equilibrium yield point will decrease.

$$Y_A{*} = Y_B{*} = Y{*} = \frac{\tau P - 4\tau C\delta\phi}{8\tau C - 4\tau\delta C - 2P} \tag{4.12}$$

4.2.3 Breeders' Decision on level of variety sharing

The third and final stage used in our backwards induction technique is for the plant breeders' to decide on the optimal amount of sharing or cooperation (δ). Again, this is the initial step taken when breeders set out to produce a new variety. To begin solving we revisit the Nash equilibrium solution from equation (4.12) and substitute that value into the plant breeders' objective function from equation (4.8) and (4.9). At this point in the game symmetry is imposed because both breeders are basing their decision on the Nash equilibrium value Y*, and the breeders' jointly determine how much they should share or co-operate with each other (δ). Thus, the condensed objective function used to find the optimal amount of sharing (δ) is shown in equation (4.13).

A transaction cost parameter is introduced into the objective function to represent the cost of sharing breeding material. Total transaction costs (φ) are a function of the amount shared (δ) and the cost of sharing (x).

$$MaxW = P\psi^* Y^* - \frac{\psi^{*2}\tau P}{2} - C(Y^{*2} - \delta Y^{*2} + Y^*\phi\delta),\ where\ \phi = \delta x \qquad (4.13)$$

Equation (4.14) shows what the objective function looks like when the Nash equilibrium yield solution is substituted. It is a very complex function with (δ) appearing in the numerator and denominator of many of the rational expressions, which would result in a very untidy and lengthy solution for the optimum δ.

$$\begin{aligned} MaxW = {} & P\psi^*\left(\frac{\tau P - 4\tau C\delta\phi}{8\tau C - 4\tau\delta C - 2P}\right) - \frac{\psi^{*2}\tau P}{2} - C\left(\left(\frac{\tau P - 4\tau C\delta\phi}{8\tau C - 4\tau\delta C - 2P}\right)^2 - \right. \\ & \left. \delta\left(\frac{\tau P - 4\tau C\delta\phi}{8\tau C - 4\tau\delta C - 2P}\right)^2 + \left(\frac{\tau P - 4\tau C\delta\phi}{8\tau C - 4\tau\delta C - 2P}\right)\phi\delta\right),\ where\ \phi = \delta x \end{aligned} \qquad (4.14)$$

Heisey and Brennan (1991) encountered a similar problem finding an optimal solution to a farmers demand for replacement seed model that they developed. Instead, they used a spreadsheet to calculate the optimum time to replace seed, and analyzed comparative statics by varying the parameters in the numerical model.

4.3 Baseline Values for the Model

A simulation using Microsoft Excel is used instead of analytical optimization techniques to find the optimal level of sharing and interpret the effects that altering transaction costs has on sharing and welfare. Table 2 shows the parameter values that were used in the simulation.

Table 2 - Parameter Values Used in Simulations

Parameter	Value
P	6
C	0.03
Ψ	0.5
Δ	0.39
T	90
X	90

The parameter values that are selected are largely arbitrary, but they are selected to ensure that all values including equilibrium yield, breeder costs, farmer benefit, and net welfare were positive. By altering the units the numbers can represent realistic scenarios.

4.4 Comparative Statics

In order to gain a greater insight on how well the model functions a comparative statics approach is used. One parameter is altered holding all others constant to gauge the effects that that particular parameter has on the Nash equilibrium yield level, total breeders' costs, total farmer benefits, and net welfare. Table 3 shows this information and presents the effects that all of the parameters in the model have on the various equations.

Table 3 - Comparative Static Analysis of the Breeders' Sharing Objective Function

p	*τ*	x	*C*	*δ*	*Ψ**	*Y**		Breeder (Total) Cost		Farmer (Total) Benefit		Net Welfare	
						% Change	Sign	% Change	Sign	% Change	Sign	% Change	Sign
5.94	90	90	0.030	0.39	0.50	-3.53		-6.13		-6.05		-5.67	
6.00	90	90	0.030	0.39	0.50	0.00	$\frac{\partial Y^*}{\partial p} > 0$	0.00	$\frac{\partial TC}{\partial p} > 0$	0.00	$\frac{\partial TB}{\partial p} > 0$	0.00	$\frac{\partial NW}{\partial p} > 0$
6.06	90	90	0.030	0.39	0.50	3.69		6.61		6.39		5.23	
6.0	89.1	90	0.030	0.39	0.50	2.30		4.10		3.78		2.08	
6.0	90.0	90	0.030	0.39	0.50	0.00	$\frac{\partial Y^*}{\partial \tau} < 0$	0.00	$\frac{\partial TC}{\partial \tau} < 0$	0.00	$\frac{\partial TB}{\partial \tau} < 0$	0.00	$\frac{\partial NW}{\partial \tau} < 0$
6.0	90.9	90	0.030	0.39	0.50	-2.16		-3.77		-3.57		-2.51	
6.0	90	89.1	0.030	0.39	0.50	0.38		0.43		0.55		1.16	
6.0	90	90.0	0.030	0.39	0.50	0.00	$\frac{\partial Y^*}{\partial x} < 0$	0.00	$\frac{\partial TC}{\partial x} < 0$	0.00	$\frac{\partial TB}{\partial x} < 0$	0.00	$\frac{\partial NW}{\partial x} < 0$
6.0	90	90.9	0.030	0.39	0.50	-0.38		-0.43		-0.55		-1.16	
6.0	90	90	0.0297	0.39	0.50	3.72		5.61		5.39		4.23	
6.0	90	90	0.0300	0.39	0.50	0.00	$\frac{\partial Y^*}{\partial C} < 0$	0.00	$\frac{\partial TC}{\partial C} < 0$	0.00	$\frac{\partial TC}{\partial C} < 0$	0.00	$\frac{\partial NW}{\partial C} < 0$
6.0	90	90	0.0303	0.39	0.50	-3.49		-5.13		-5.05		-4.66	
6.0	90	90	0.030	0.3861	0.50	-0.03		-0.04		-0.05		-0.10	
6.0	90	90	0.030	0.3900	0.50	0.00	$\frac{\partial Y^*}{\partial \delta} > 0$	0.00	$\frac{\partial TC}{\partial \delta} > 0$	0.00	$\frac{\partial TC}{\partial \delta} > 0$	0.00	$\frac{\partial NW}{\partial \delta} > 0$
6.0	90	90	0.030	0.3939	0.50	0.02		0.03		0.03		0.07	
6.0	90	90	0.030	0.39	0.495					-0.56		-3.50	
6.0	90	90	0.030	0.39	0.5	N/A		N/A		0.00	$\frac{\partial TC}{\partial \psi^*} > 0$	0.00	$\frac{\partial NW}{\partial \psi^*} > 0$
6.0	90	90	0.030	0.39	0.505					0.55		3.44	

Table 3 and Figure 4 are used together to better explain the results of the model. Each curve in Figure 4 shows how a change in the amount shared (δ) affects net welfare holding all other parameters constant. The transaction cost parameter (*x*) is only varied with each curve. Net welfare curves for the three transaction cost levels (*x* = 80,90 and 100) are calculated as total welfare that farmers receive from the new variety (A or B) minus total costs that the breeders incur to produce the new variety (A or B). The maximum point (slope = 0) on each of the three curves corresponds to the point where marginal benefit is equal to marginal cost and changes as the transaction costs change. Figure 3 shows that as transaction costs increase (comparing x = 90 to x = 100) the plant breeders compensate by deciding to share less which results in a loss of net welfare to farmers. As transaction costs decrease (comparing x = 90 to x = 80) breeders' choose to share more and there is a gain in net welfare to farmers.

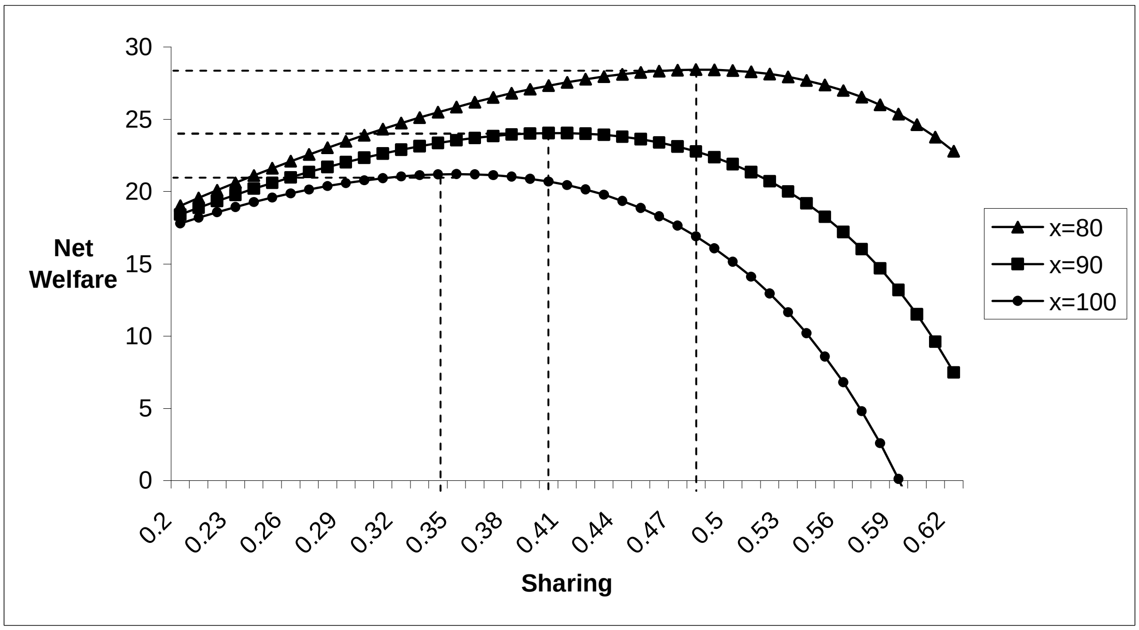

Figure 4 - Net Welfare Changes as Transaction Costs Change

The data in Table 3 showing the effects of different sharing levels on net welfare is representative of the increasing part of the curve *x* = 90 in Figure 3. The curve is increasing from the origin to $\delta \approx 0.4$ .From the point where $\delta \approx 0.4$ outward the curve is decreasing. This result is important to understand when considering the results presented in Table 3 for δ. If the sharing levels used for comparison in Table 3 were greater than

0.4 instead of less than the 0.4 that was used, the four results reported would be decreasing instead of increasing as reported in Table 3.

This is an important result as it shows that net welfare increases when breeders share to a certain point, then it decreases as they share more. For clarification, it is helpful to think of the extremes: sharing no germplasm with other breeders and sharing all germplasm with other breeders. If a breeder that doesn't share any germplasm at all, then other breeders will not want to share any germplasm back. Breeders do not have the incentive to share if they know that they will not receive anything for their efforts. The breeder not sharing anything has a lot to gain by starting to share a small amount. Conversely, the breeder who concentrates on sharing everything that is developed is sacrificing his own breeding program. It takes time and effort to share the results of plant breeding activities; any time spent sharing takes time away from time spent breeding. The curves in Figure 4 represent this situation.

All of the other parameters used in the model were also analyzed for their local effects near the optimal sharing point. As output price (P) increases the Nash equilibrium yield level (Y^*) increases. This is explained by a change in the value of the breeders' marginal product when the output price changes. If the farmer's output price is low for the crop that the breeder is improving then the higher yields produced are worth less than if the price was higher.

Individual wheat breeder costs (*TC*) rise as the output price rises. This effect is derived from the positive effect that price has on yield level. The cost function is specified so an increase in yield level will result in an increase in a breeder's costs. Thus, increased yield level from the increase in price increases a breeder's costs.

Total farmer benefit (*TB*) from the variety also increases as the output price rises. This effect is relatively straight forward. If everything else is held equal and the output price increases then farmer benefits are sure to increase from growing the new variety.

An increase in output price results in an increase in net welfare (*NW*). Consequently, the increase in farmer benefits from a price increase is greater than the increase in breeder costs from a price increase. This is to be expected as an increase in the price of the commodity makes everyone better off.

Again, τ is used to show how much the yield decreases as the farmers differentiate from the optimum sites for the variety ($\Psi = 0$ or 1 depending on A or B). Across all four equations τ has a negative effect on the solution. The analytical model shows that as τ increases the Nash equilibrium yield decreases. Farmer benefits from a new variety decrease as τ decrease.

The transaction cost parameter (*x*) and the cost constant parameter (*C*) both have a negative effect on all four equations. Initially the increased costs result in a lower Nash equilibrium yield that the breeders target. Because it becomes more expensive to increase yield incrementally, the Nash equilibrium yield is lowered. However, the breeder total cost function also decreases as the transaction and constant cost parameters increase. At first this seems like a rather perverse result, having the cost parameters increase but the total cost for breeding a variety decrease. It is not entirely unrealistic though as they are not breeding for as high a yield anymore. Breeding for a lower yield lowers the breeder's costs. This effect flows through to the farmer benefits as they decrease with the higher transaction and constant costs. The lower yielding variety that is produced results in lower benefits as well. Finally, the increased costs have a negative effect on net welfare. The decrease in breeding costs is offset by the decrease in farmer benefits, resulting in a net welfare decrease.

4.5 Conclusion and Policy Implications

Policy decisions that may affect the availability of plant breeding materials need to be examined for their flow through effects on public plant breeders freedom-to-operate. When governments are making policy decisions that affect public plant breeders they need to be cognizant of the fact that policy decisions on public breeders not only affect breeders but they also filter down to the farm level. The model shows that policy choices that increase transaction costs on the crucial interactions between public plant breeders will end up lowering farmer welfare. Policy choices that are perceived to create incentives to innovate among public plant breeders (e.g. stronger breeder rights) may, in fact, cause the opposite effect and create disincentives for innovation among public plant breeders.

5 Pedigree Analysis

In order to understand what may happen to plant breeding in the future, a look into past plant breeding activities is helpful. To keep track of the sources of genetic variation used by plant breeders to create new varieties a pedigree is used. Record keeping through pedigrees allows breeders to track improvements and make further improvements more efficient. Depending on the type of crop and the organization doing the breeding work the pedigree for a variety may or may not be available to the general public.

The purpose of chapter 5 is to explore the pedigrees of registered CWRS wheat varieties and then relate the number of sources of genetic variation used in existing varieties to future CWRS breeder's freedom-to-operate potential. The chapter is organized into 4 sections. Section 5.1 provides a background to the CWRS wheat class in Western Canada, showing which varieties are grown in the region and what types of organizations have registered varieties. Section 5.2 develops the methodology used to conduct the pedigree analysis. Sub-sections are devoted to explaining the significance of two key dates in a typical breeding program, explaining the data sources, and explaining the logical decision trees that were used to assign the breeding lines to the various classes. Section 5.3 presents and discusses the results of the analysis framing the results in the freedom-to-operate context. Section 5.4 concludes the results and the chapter.

5.1 Introduction

In Western Canada there are eight different classes of wheat grown by farmers. Classes such as Canadian Prairie Spring Red and White (CPSR and CPSW) and Canadian Western Red Winter (CWRW) are typically grown for the domestic feed market. Classes such as Canadian Western Soft White Spring (CWSWS), Canadian Western Extra Strong (CWES), Canadian Western Red Spring (CWRS), Canadian Western Hard White (CWHW), and Canadian Western Amber Durum (CWAD) are typically grown for both the export and domestic milling market. Although there are many different classes of wheat grown in Western Canada, acreage is dominated by two classes. CWRS and CWAD varieties were grown on 69.7% and 21.1% of the landbase devoted to wheat production in 2006 (CWB 2006).

Of particular interest to this thesis is the CWRS category. Table 4 presents the CWRS varieties grown in western Canada and the distribution of total acreage devoted to a particular variety in 2006. A pedigree analysis was carried out for each variety bolded in Table 4. Superb and AC Barrie are the two most popular varieties followed by a fairly even distribution of all of the other varieties.

Table 4 - Distribution of Acreage Devoted to Specific CWRS varieties in Western Canada. (G=Publicly Bred, P = Privately Bred, U = University Bred

Variety	Prairie Average	Variety	Prairie Average	Variety	Prairie Average
Superb (G)	18.3%	AC Splendor (G)	3.7%	5602 HR (P)	0.8%
AC Barrie (G)	17.8%	**Lillian** (G)	3.6%	5601 HR (P)	0.7%
Mckenzie (P)	9.4%	Other	3.4%	**Journey** (P)	0.4%
Harvest (G)	5.6%	**CDC Imagine** (U)	3.3%	Lovitt	0.3%
AC Intrepid (G)	5.5%	**AC Cadillac** (G)	3.0%	5600HR (P)	0.2%
Prodigy (P)	4.7%	AC Elsa (G)	2.3%	5500HR (P)	0.2%
AC Eatonia (G)	4.5%	**AC Abbey** (G)	1.7%	**Infinity** (G)	0.2%
AC Domain (G)	3.9%	Columbus (G)	1.4%	CDC Go (U)	0.1%
CDC Teal (U)	3.9%	**CDC Bounty** (U)	1.1%	CDC Osler (U)	0.1%

Source: Adapted from CWB 2006

There are three types of organizational structures that have recently registered CWRS wheat varieties in Western Canada. Agriculture Canada has breeding stations in Swift Current and Winnipeg. The University of Saskatchewan hosts the Crop Development Centre. Finally, two private companies: Agri-Pro and Saskatchewan Wheat

Pool each have registered varieties[10]. The varieties that each of these organizations have released are listed in Table 4. In brackets following the variety name the letter G denotes an Agriculture Canada variety, the letter U denotes a U of S variety, and the letter P denotes a private company's variety.

5.2 Methodology used for Pedigree Analysis

The success of a plant breeding program is directly related to the breeders' ability to directly access genetic variation (McCouch 2004). Typical sources of genetic variation that CWRS breeders use include registered CWRS varieties, breeding lines from their own program, breeding lines from other CWRS breeders programs, breeding lines from other country's wheat breeding programs, and to a very limited extent landraces. These sources are combined in a variety of ways to create a new variety[11].

The analysis is used to explore two important elements about the germplasm that CWRS breeders use in their breeding programs. The first part of the analysis classifies all of the breeding lines used (germplasm base) for CWRS variety development either as registered varieties or unregistered homozygous lines. The second part of the analysis

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[10] Agri-Pro's varieties are distributed by Agricore United

[11] Columbus is an example of the importance of registered varieties as a source of genetic variation. Of the top six varieties listed in table 4 Columbus was used in the breeding of every variety except for Superb. Also, CDC Teal was used in the breeding of both Prodigy and AC Intrepid.

considers the origins of the germplasm base and which organization created the breeding line

To begin the analysis data was gathered about the pedigrees of each registered variety from a combination of sources. The data was then entered into Microsoft Excel, and logical statements were used to sort the breeding lines into the various desired categories. The results from the individual varieties were then aggregated according to the organizational structure that bred the variety.

5.2.1 Key Dates in Variety Development

For the purposes of this thesis two important dates in the creation of a new variety are recognized. The first date of importance is the time when the breeder starts to make crosses and combine sources of genetic variability. After the initial crosses it takes anywhere from 8-12 years of selecting, seed bulking, and testing before the variety can be eligible for registration. Thus, the second important date is when the variety is finally accepted for registration and protected with plant breeders' rights. Commercialization and protection with breeders' rights are independent events that may occur over two specific times. Quite often a variety is first commercialized and then plant breeders' rights are sought afterwards. Generally though the date of commercialization and granting of plant breeders rights occur fairly close together and are quite distinct from the date that initial crosses are made.

The period between when these two important dates occur is important for analyzing the rights that creators of breeding lines may potentially have on newly created varieties. Figure 5 outlines how these two dates may interact; showing three possible scenarios with three different varieties bred using variety A as a breeding line. For varieties B and D the rights that the creator of variety A has are clear, however for variety C the rights that the owner of variety A has is uncertain.

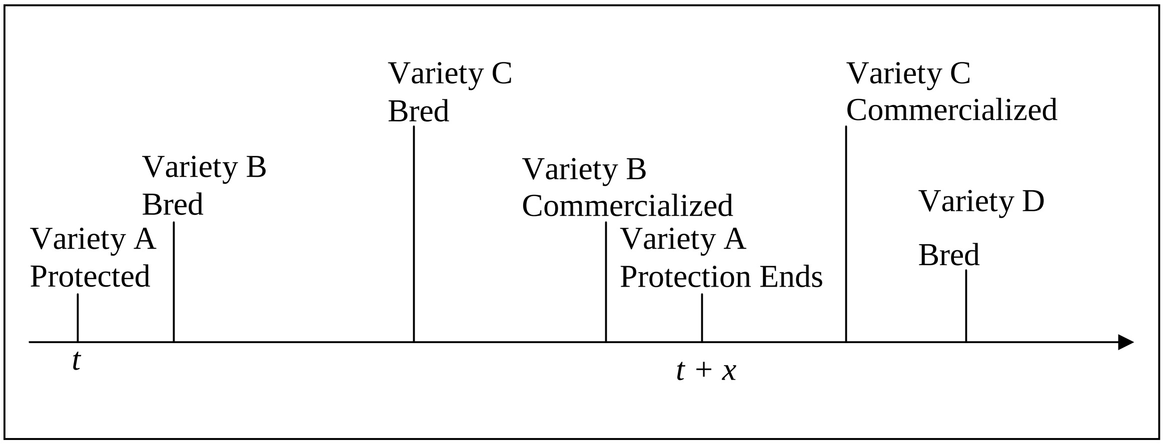

Figure 5 - Timeline for Variety Protection

Variety A is protected using PBRs at time *t* and the length of time that it is to be protected for is equal to *x*. Therefore, variety A's protection will expire at time *t*+*x*. In the case of variety B it is initially bred using variety A as a breeding line and then commercialized before the protection period of variety A expires. It is clear that the creator of variety A would be eligible to whatever rights the PBR system allows over the revenue generated by variety B[12].

Variety D is also bred using variety A as a breeding line. However, variety A is not used in the creator of D's breeding program until after the owner of variety A's rights have expired. Given that variety A was not used until after the expiration of A's PBRs,

[12] The mechanism that would allow this would be essential derivation principle

the creator of variety A would have not rights over the revenue generated by variety D upon its commercialization.

The uncertainty under this scenario arises with variety C. Variety C was bred using variety A as a breeding line during the time that variety A was under protection. However, variety C was not commercialized until after variety A's protection had expired. According to the Plant Breeders Rights office (PBRO) variety C would be considered to have the same status as variety D, that the creator of variety A would have no rights over variety C. The PBRO interprets the proposed changes to the *Plant Breeders' Rights* Act to only apply from commercialization of one variety to commercialization of another. The organization does not believe that the time when a variety was used in a breeding program is significant[13]. Therefore, being as variety C was commercialized after variety A's protection expired, the creator of variety A would have no rights to the revenue generated by variety C. Unfortunately, this interpretation has never been verified by a legal decision because the proposed changes to the *Plant Breeders' Rights* act have not been implemented yet.

Other developed countries such as Australia and some nations within the European Union have had UPOV 1991 based PBRs for some time. There have been very few court cases involving the PED and no court cases involving wheat varieties. In the whole EU there has been only one case which involved a type of flower called *Gypsophilia.* The case of Astee Flowers v. Danziger Flower Farm (2005) resulted in a decision which considered one variety to not be essentially derived from another. In

[13] Personal Communications with Valerie Sisson, Commissioner of the Plant Breeders Rights Office

Australia, there have been two cases which involved accusations of essential derivation in *Stenotaphrum*. One case is still pending and the other had been ruled that the accused variety is not essential derived from the accusers (Waterhouse 2005). In our limited case-law search there have been no successful PED challenges and no challenges over wheat varieties.

For the remainder of this chapter we consider both scenarios relative to variety A. Variety C is treated like it has equivalent status to variety B in one instance and then variety C in another.

5.2.2 Data Sources

Data for the analysis was obtained from four different sources. Primarily, AAFC's contributions to the International Crop Information System (ICIS) database were used. This database provides a comprehensive listing of the complete pedigrees of all registered CWRS varieties. Although it provides excellent information about the particular breeding lines used it is missing information about the dates that some varieties were registered or when some unregistered homozygous lines were created. In order to fill in this missing information CIMMYT's directory of registered varieties was used as a search engine to locate published registration papers and plant variety protection certificates. These papers and certificates used to verify dates were located in the *Canadian Journal of Plant Science*, *Crop Science*, and the *Plant Varieties Journal*. Unfortunately, there were some American unregistered homozygous lines that dates were not available for. The dates used for theses lines were estimated using information embedded in other breeding lines of the pedigree. If it was felt that an accurate estimate could not be made about the date of a particular breeding line, the breeding line was given a date close to the release date, so the line would be included in all scenarios[14].

5.2.3 Breeding Line Composition Analysis

The breeding lines were separated into registered and unregistered breeding lines. Registered lines are easily attainable through breeder seed from any seed distributor or gene bank. Under the current PBR system there are no conditions to be met when using a registered variety for germplasm. Unregistered lines are marginally more difficult to attain, generally these lines are only attainable through the breeding line creator and a material transfer agreement (MTA). This is an important distinction because any claims of essential derivation can only be used on protected varieties, not unprotected breeding lines. However, it could be easily written into any MTA that royalty revenue be shared between the signatories of the MTA.

The procedure used to determine the status of a particular breeding line is outlined in Figure 6. First the date that the breeding line was registered or became eligible for testing is examined. If the date falls within the chosen timeframe the next decision is if the variety is registered or not. The phrases bolded in Figure 6 represent the categories that the breeding lines were sorted into.

[14] This results in an upward bias of some of the results, but this process was used sparingly on three breeding lines.

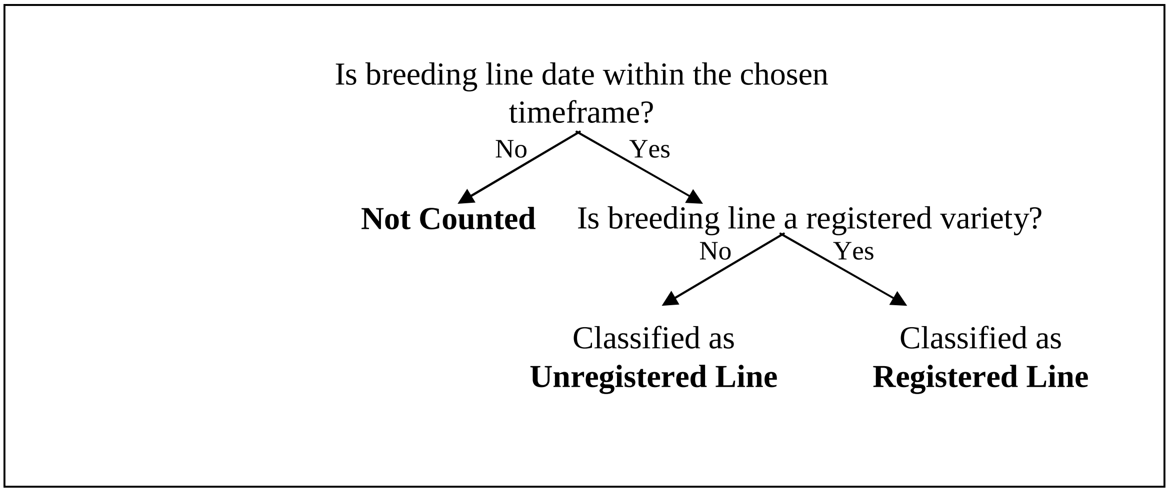

Figure 6 - Decision Tree used for assigning registration status to breeding lines

5.2.4 Origins of Germplasm Analysis

CWRS wheat breeders access both registered and unregistered breeding lines from different types of organizations around the world as well as their own program. The procedure used to classify the origins of these breeding lines starts in a similar manner to the procedure used to judge the registration status in section 5.2.3. The full decision process is shown in Figure 7 and represents a more complex decision process than that of Figure 6. The phrases bolded in Figure 7 represent the categories that the breeding lines were sorted into

For varieties produced at AAFC CWRS breeding stations there are 5 different classes for the breeding lines. The *landrace* class refers to unimproved breeding lines available though gene banks such as CIMMYT. *Foreign* breeding lines originate from any other country than Canada, including the USA[15]. These lines can come from public, private or university wheat breeders. The last 3 classes refer to domestic breeding lines. The breeding lines that fall into the *university/other* class include breeding lines developed at Canadian universities and other non-AAFC government wheat breeders[16]. Breeding lines previously developed at the breeding station that produced the variety being analyzed are classified as *own public station*, and breeding lines produced at other government stations are classified as *other public station*.

For varieties produced at the CDC and by private companies there are 7 different classes used to classify the various breeding lines. Similar to AAFC, the *landrace* class refers to unimproved breeding lines. *Foreign* breeding lines originate from any other country than Canada. *Public* breeding lines refer to those developed by AAFC as well as any other government breeder. For CDC varieties the remaining two classes used include *own university* and *other university/private company*. Obviously, CDC breeding lines would fall into the *own university class* and all other university and private lines fall into the *other university/private company* class. Breeding lines created by the private company that produced the variety being analyzed are classified as *own private company*, while breeding lines created by other private companies and universities are classified as *other private company/university.*

[15] In the analysis it was found that there are breeding lines used that originated from Chile, Mexico, Argentina, and France.

[16] There were no private breeding lines used by AAFC CWRS breeders.

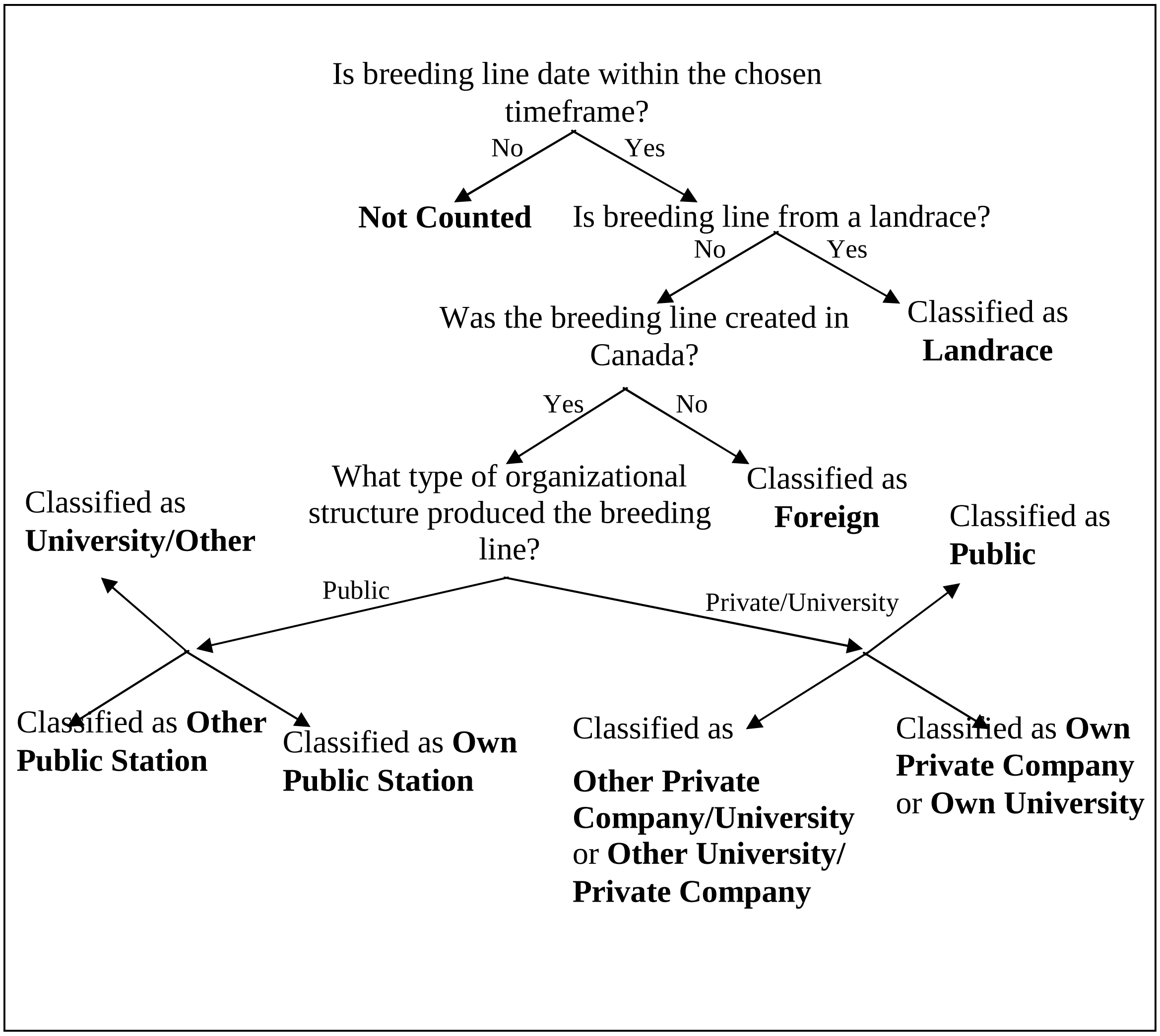

Figure 7 - Decision tree used for assigning breeding line ownership

5.3 Results and Discussion

In this section the results from the pedigree analysis are reported and discussed. A 20 year time limit (*t*) was used to form a baseline for comparisons. Twenty years was chosen because for registered varieties because that is within the timeframe when rights to a variety will expire. Although this time limit does not necessarily apply to unregistered breeding lines a time limit still had to be assigned to them, so 20 years was chosen.

The first part of this section describes the prevalence of registered varieties in the three different organizational CWRS breeding programs. The second part describes the origins of the various breeding lines that are used in the three types of organizational CWRS breeding programs.

5.3.1 Breeding Line Composition

For all three types of CWRS breeding organizations there is a drastic difference in the number of breeding lines that fall within the set 20 year time limit of the initial cross and registration date. In all cases the initial cross year resulted in a greater number of breeding lines being included in the total than the registration year. This is due to the larger time period associated with the initial cross year compared to the registered year.

For the AAFC bred varieties there is no instance where the number of registered varieties made up more than half of the total number of breeding lines used (Table 5). Using the initial cross year for comparison, AC Barrie had the greatest number of registered lines, with 4 of 8 breeding lines representing registered varieties. AC Intrepid had the least number of registered lines as a proportion of its total, utilizing 4 registered varieties out of 20 total breeding lines. The average for this category shows that about one third of the total number of breeding lines used by AAFC breeders to produce varieties is registered lines.

For all of the AAFC varieties the numbers are similar when using the variety registration year for comparison compared to the initial cross year for comparison. Again, AC Superb had the greatest proportion of registered varieties, with 2 out of 5 breeding lines being registered varieties. AC Cadillac had the smallest proportion of registered varieties, utilizing 1 registered variety out of 6 total breeding lines. The aggregate for the registered year comparison was that on average one third of the total number of breeding lines used by AAFC breeders are registered lines.

Table 5 - Composition of Breeding Lines in AAFC Bred CWRS wheat Varieties

AAFC Varieties		Infinity	AC Superb	AC Cadillac	AC Abbey	AC Barrie	Lillian	Harvest	AC Intrepid	Averages
Initial Cross Year *t*=20	Registered Lines	5	4	2	4	5	3	3	4	4
	Unregistered Lines	13	4	7	10	6	7	5	16	9
	Total Breeding Lines	18	8	9	14	11	10	8	20	12
Registration Year *t*=20	Registered Lines	2	2	1	1	2	1	1	4	2
	Unregistered Lines	6	3	5	3	6	2	3	8	5
	Total Breeding Lines	8	5	6	4	8	3	4	12	6

Using the initial cross year as a comparison the privately bred CWRS wheat varieties had a higher utilization of registered varieties in their breeding program compared to AAFC (Table 6). Mckenzie had the greatest proportion of registered lines, with 3 of 5 breeding lines used being registered varieties. Prodigy had the smallest proportion of registered lines used, with 3 out of 10 breeding lines being registered varieties. Across all private varieties slightly more than half of the breeding lines used were registered.

Using the registration year as a comparison the results are very similar. Mckenzie used 2 registered varieties out of 3 total breeding lines which represented the greatest proportion. Prodigy used 2 registered varieties out of 8 total breeding lines which represented the smallest proportion. Again, across all private varieties slightly more than half of the breeding lines used were registered varieties.

Table 6 - Composition of Breeding Lines in Private Company Bred CWRS wheat Varieties

Private Company Varieties		Prodigy	Mckenzie	Journey	Averages
Initial Cross Year *t* =20	Registered Lines	3	3	8	5
	Unregistered Lines	7	2	6	5
	Total Breeding Lines	10	5	14	10
Registration Year *t* =20	Registered Lines	2	2	4	3
	Unregistered Lines	6	1	3	3
	Total Breeding Lines	8	3	7	6

Comparing the initial cross year data across the university bred wheat varieties shows that the average proportion of registered lines in the pedigrees is greater than that of the AAFC varieties but less than that of the private varieties (Table 7). CDC Bounty had 4 registered lines out of 6 total breeding lines, which was the highest proportion of university bred varieties. CDC Imagine had 1 registered variety out of 5 total breeding lines which was the lowest proportion of university bred varieties. On average university bred varieties have less than half of their breeding lines as registered varieties.

Comparing the registration year data for the university bred wheat varieties yields different results than the initial cross year data. CDC Bounty and CDC Imagine both had the same proportion of the total number of breeding lines as registered lines, 2 out of 4 and 1 out of 2 respectively. CDC Teal had the smallest proportion of registered lines as 2 out 6 breeding lines were registered. Averaging the data across the three varieties shows that close to half of the breeding lines used for the varieties were registered lines.

Table 7 - Composition of Breeding Lines in University Bred CWRS wheat Varieties

University Varieties		CDC Teal	CDC Bounty	CDC Imagine	Averages
Initial Cross Year *t* =20	Registered Lines	5	4	1	3
	Unregistered Lines	5	2	4	4
	Total Breeding Lines	10	6	5	7
Registration Year *t* =20	Registered Lines	2	2	1	2
	Unregistered Lines	4	2	1	2
	Total Breeding Lines	6	4	2	4

5.3.2 Origins of Germplasm

Across all pedigrees for the varieties analyzed there was only 1 breeding line that came from a landrace type origin. Mckenzie used one unimproved line from the CIMMYT gene bank in Mexico. All of the other breeding lines in the varieties were improved and selected for. CWRS breeders have not actively sought genetic variation for unimproved sources for the current popular varieties. However, this could change in the future with the ongoing search for improved UG-99 rust resistance as scientists have found promising resisting genes in some landraces (Anonymous 2006).

It is interesting to speculate on the reasons why CWRS breeders have not sought genetic variation from unimproved sources for their breeding programs. In Canada there is a very strict variety registration process which incorporates the principle of Kernel Visual Distinguishability(KVD). KVD requires that any new varieties in a particular class must be visually distinguishable from all other classes. This affects breeders ability to incorporate new genetics into their breeding program. Perhaps, the different kernel shapes that result from a cross between two plants with diverse kernel types are too cumbersome to breed back to the required KVD standards.

Some AAFC varieties rely heavily on foreign breeding lines for their germplasm base and others rely very little on foreign breeding lines (Table 8). Using the registration year for comparison, the varieties AC Superb, Harvest, and Infinity contain genetics from 4 foreign lines out of 5 total lines, 3 foreign lines out of 4 total lines, and 6 foreign lines out of 8 total lines respectively. If the initial cross year is used for comparison instead of the registration year the foreign content of these varieties becomes numerically diluted at 6 foreign lines out of 8 total lines for AC Superb, 4 foreign lines out of 8 total lines for Harvest, and 6 foreign lines out of 18 total lines for Infinity. Conversely, varieties such as AC Abbey and AC Barrie contain very little foreign bred germplasm. For the registration year comparison both varieties used no foreign lines. However, if the initial cross year is used then the foreign content numerically increases to 1 foreign line out of 14 total lines for AC Abbey and to 3 foreign lines out of 11 total lines for AC Barrie. Interestingly, when the two most popular varieties grown in Western Canada, AC Superb and AC Barrie, are compared, AC Superb relies heavily on foreign breeding lines and AC Barrie hardly at all.

With one exception, AAFC CWRS wheat breeders are dependent on breeding lines from outside their breeding station as a source of genetic variation. For the registration year comparison AC Abbey has 3 breeding lines out of 4 total lines and Lillian has l breeding line out of 2 total lines originating from the AAFC Swift Current breeding station. All of the other varieties utilize either no lines from their own station or 1. Importantly, AC Barrie was created exclusively using breeding lines from outside sources. For the initial cross year comparison the situation is similar; again, AC Abbey has 10 breeding lines out of 14 total lines from its parent AAFC Swift Current program and Lillian utilizes 5 breeding lines out of 10 total lines from its parent AAFC Swift Current program. All of the varieties contain a low percentage of breeding lines from their own program.

Although AAFC CWRS wheat breeders are dependent on breeding lines from outside of their station for genetic variation, they are less dependent on breeding lines from outside the AAFC organization. With the exception of the varieties with a large amount of foreign germplasm, the majority of the breeding lines of the remaining varieties come from other AAFC breeding stations. For the registration year comparison AC Intrepid, AC Barrie, AC Cadillac are three AAFC Swift Current varieties which use very few breeding lines from their own programs, 1 breeding line out of 12 total, 0 breeding lines out of 8 total, and 0 lines out of 6 total respectively. Instead they use a large amount of breeding lines from the AAFC Winnipeg program, 7 breeding lines out of 12 total, 5 breeding lines out of 8 total, and 5 breeding lines out of 6 total lines respectively. Using the initial cross year as a comparison the situation is similar again. AC Intrepid used 10 breeding lines out of 20, AC Barrie used 5 breeding lines out of 11, and AC Cadillac used 6 breeding liens out of 9 total from the AAFC Winnipeg program.

Table 8 - Origins of Breeding Lines used in AAFC Bred CWRS Wheat Varieties

Breeding Line Origin		Government Varieties								Averages
		Infinity	AC Superb	AC Cadillac	AC Abbey	AC Barrie	Lillian	Harvest	AC Intrepid	
Initial Cross Year *t* =20	Landrace	0	0	0	0	0	0	0	0	0
	Foreign	6	6	2	1	3	1	4	1	3
	University/Other	2	0	1	1	3	1	2	5	2
	Own Public Station	5	2	0	10	0	5	2	4	4
	Other Public Station	5	0	6	2	5	3	0	10	4
	Total AAFC Lines	10	2	6	12	5	8	2	14	7
	Total Domestic Lines	12	2	7	13	8	9	4	19	9
	Total Breeding Lines	18	8	9	14	11	10	8	20	12
Registration Year *t* =20	Landrace	0	0	0	0	0	0	0	0	0
	Foreign	6	4	1	0	0	1	3	1	2
	University/Other	0	0	0	0	3	0	1	3	1
	Own Public Station	1	1	0	3	0	1	0	1	1
	Other Public Station	1	0	5	1	5	1	0	7	3
	Total AAFC Lines	2	1	5	4	5	2	0	8	3
	Total Canadian Lines	2	1	5	4	8	2	1	11	4
	Total Breeding Lines	8	5	6	4	8	3	4	12	6

Two private company bred lines utilized a large amount of foreign origin breeding lines (Table 9). Using the registration year for comparison, Prodigy had 4 foreign breeding lines out of 8 total lines and Journey had 5 foreign breeding lines out of 7 total lines. If the initial cross year is used the proportion of foreign lines is similar for Prodigy but decreases for Journey. Prodigy had 5 foreign lines out of 10 total lines and Journey had 7 breeding lines out of 14 total lines.

Mckenzie had a relatively small number of breeding lines with an even distribution across the classes compared to the other private varieties. For the registration year Mckenzie used 1 landrace, 1 foreign line and 1 public line for a total of 3 lines. The distribution is similar if the initial cross year is used: 1 landrace, 2 foreign lines, and 2 public lines for a total of 5 lines.

Interestingly, none of the private varieties used a large number of breeding lines from their own program. For the registration year Prodigy and Journey used 1 breeding line out of 8 total lines and 1 breeding line out of 7 total lines from their own program. In the initial cross comparison the number of private lines becomes numerically diluted, with Prodigy using 1 breeding line out of 10 and Journey using 1 breeding line out of 14 total lines from their own program. Mckenzie used no breeding lines from its own program in both comparisons.

Table 9 - Origins of Breeding Lines used in Private Company Bred CWRS wheat Varieties

Breeding Line Origin		Private Varieties			Averages
		Prodigy	Mckenzie	Journey	
Initial Cross Year *t* =20	Landrace	0	1	0	0
	Foreign	5	2	7	5
	Public	2	2	3	2
	Own Private Company	1	0	1	1
	University/Other Private	2	0	3	2
	Total Domestic Lines	5	2	7	5
	Total Breeding Lines	10	5	14	10
Registration Year *t* =20	Landrace	0	1	0	0
	Foreign	4	1	5	3
	Public	1	1	0	1
	Own Private Company	1	0	1	1
	University/Other Private	2	0	1	1
	Total Domestic Lines	4	1	2	2
	Total Breeding Lines	8	3	7	6

Although three university lines were analyzed there are only two different pedigrees for the three varieties. CDC Imagine was developed using mutagenesis techniques from CDC Teal. Essentially, CDC Imagine and CDC Teal have the same pedigree the only difference being CDC Teal is part of CDC Imagines pedigree. The difference in the distribution of breeding lines in Table 10 is caused by the time limit from when CDC Imagine was bred and then released compared to when CDC Teal was bred and released.

Similar to the variety Mckenzie, CDC Teal had a fairly even distribution of its breeding lines across three classes. For the registration year comparison CDC Teal was created using 2 breeding lines from each of the foreign, public, and own university classes. The distribution is similar if the initial cross year is used for comparison. In this comparison CDC Teal used 2 foreign lines, and 4 breeding lines each from the public and own university classes.

CDC Teal was created using a higher amount of foreign varieties than CDC Bounty. For the registration year comparison 2 breeding lines out of 6 total lines were foreign for CDC Teal, and 0 breeding lines out of 3 total lines were foreign for CDC Bounty. If the initial cross year is used for comparison CDC teal used 4 foreign lines out of 10 total lines compared to CDC Bounty which used 0 foreign lines out of 4 total lines.

Two university bred varieties rely almost exclusively on CDC breeding lines for their genetic variation. For the registration year comparison all of CDC Bounty's and CDC Imagines' breeding lines were from the CDC. If the initial cross year is used 3 breeding lines out of 4 total lines found in CDC Bounty and 2 breeding lines of 3 total lines found in CDC Imagine originated from the CDC.

Table 10 - Origins of Breeding Lines used in University Bred CWRS wheat varieties

Breeding Line Origin		University Varieties			Averages
		CDC Teal	CDC Bounty	CDC Imagine	
Initial Cross Year *t* =20	Landrace	0	0	0	0
	Foreign	4	0	0	1
	Public	4	1	1	2
	Own University	2	3	2	2
	Private/ Other University	0	0	0	0
	Total Domestic Lines	6	4	3	4
	Total Breeding Lines	10	4	3	6
Registration Year *t* =20	Landrace	0	0	0	0
	Foreign	2	0	0	1
	Public	2	0	0	1
	Own University	2	3	2	2
	Private/ Other University	0	0	0	0
	Total Domestic Lines	4	3	2	3
	Total Breeding Lines	6	3	2	4

5.4 Freedom-to-Operate Analysis

Referring back to the definition of freedom-to-operate given earlier (section 2.2) helps to put the results of the previous section into context with the objective of the thesis. Freedom-to-operate is just as it implies – the freedom to use the unlicensed property of others without being legally restricted. In this section the results of the previous section are linked to the freedom-to-operate problem.

Backcross breeding has been an important technique used by Canadian wheat breeders to create new wheat varieties. In the pedigree analysis 3 out of the 14 varieties (Superb, Lillian, and Cadillac) were created with a backcross. Combined, these three varieties were grown on approximately 25% of the CWRS acres planted in 2006 (CWB 2006). Given that backcrossing is one of the breeding techniques that fall under the scope of PED (section 3.4.1) one can make the extension that if the proposed amendments to the PBR act had been in place before the registration of these varieties, these three varieties would be considered essentially derived from there respective parents.

Mutagenesis breeding has not been as prevalent as backcross breeding in wheat variety development; nevertheless the technique has still been used by wheat breeders. CDC Imagine was grown on 3.3% of the CWRS acreage in 2006 (CWB 2006). It was the first, and so far the only variety that has been created using this technique. CDC Imagine and CDC Teal show how the essential derivation/initial variety scenario could play out. CDC Imagine was bred using mutagenesis techniques from CDC Teal which would give these two varieties an essential derivation relationship. It is interesting to note that both CDC Imagine and CDC Teal were bred at the Crop Development Centre in Saskatoon. Whether or not the creators of CDC Imagine chose CDC Teal to work with because of familiarity with the variety or because of FTO concerns is unknown.

It is also interesting to speculate on what varieties would have been released and available to farmers if there would have been restrictions on the flow of germplasm for the last century or freedom-to-operate concerns. If access to germplasm from outside of the country had been restricted popular varieties such as AC Superb, Harvest, and Infinity may have never been created as they relied heavily on foreign bred germplasm. In fact, AC Superb is a great example of the give and take that has been present between Canadian and American in wheat breeders over the last century. AC Superb was created using mostly American varieties that had been developed using a Canadian bred variety, Marquis, as a distant parent.

5.5 Conclusion

All of the varieties that were analyzed used at least one registered variety in their creation. For the initial cross comparison private company varieties had a higher prevalence of registered varieties in their pedigrees, followed by university varieties, and then by AAFC varieties. Using the registration year for a comparison all three types of breeding organizations had a similar utilization of registered varieties in the pedigrees.

For all of the AAFC varieties there is not one dominant origin of breeding line material. AC Superb, Harvest, and Infinity utilize a large amount of foreign breeding lines. AC Cadillac, AC Barrie and AC Intrepid were created almost entirely using breeding lines from outside the parent program sources, in particular the other AAFC breeding station. Finally, the solid stemmed varieties AC Abbey and Lillian were created with a large proportion of breeding lines from their own breeding station. Comparing the two dates used for comparison, initial cross year and registration year, there is not much of a difference in the classification of the varieties as foreign based, own station dependent, and other station dependent. However, there is a difference in the magnitude of the varieties involved in the pedigrees. If the initial cross year is used in all cases the number of breeding lines counted in the pedigree increases.

Of the 6 private and university bred varieties analyzed comparisons and contrasts can be made using various varieties. CDC Teal and McKenzie both do not have a standout class that their sources of genetic variation originate from. The private company lines Prodigy and Journey have a large number of foreign breeding lines in their pedigrees, compared to the university bred varieties CDC Bounty and CDC Imagine which have none. Instead, CDC Bounty and CDC Imagine relied almost exclusively on breeding lines from the CDC program.

Analysis of the varieties in the pedigree analysis show potential FTO problems for wheat breeders. Two breeding techniques, backcross breeding and mutagenesis, used by CWRS breeders fall under the scope of the PED. Four significant wheat varieties (AC Superb, Lillian, AC Cadillac, and CDC Imagine) which are grown on over 28% of the prairie CWRS acreage have been created using these techniques.

6 Concluding Remarks

This thesis examines sharing of germplasm between plant breeders using written, theoretical, and empirical arguments. In the third chapter an analogy between the open source software movement and wheat breeding in Canada is developed using incremental improvements in both industries as a theme for comparison. The fourth chapter of the thesis presents a theoretical model showing how increasing the cost of sharing germplasm between plant breeders will result in breeders lowering their yield goals and ultimately decreasing farmer welfare from using the varieties. Finally, the fifth chapter presents data on the origins of breeding lines and the use of registered varieties in CWRS wheat breeding in Western Canada. A common conclusion between all of the chapters is that the sharing of germplasm between plant breeders is vitally important for the success of the industry.

When discussing plant breeders rights it is important to separate out the parties that plant breeders need to create excludability from. The thesis does not try to distinguish whether or not farmers should be able to save seeds from registered varieties. Rather, it shows that excluding rival breeders from germplasm stocks will result in a decrease in the efficiency of plant breeding.

6.1 Summary

In the first chapter of the thesis (section 1.2) two hypotheses were put forward regarding potential freedom-to-operate issues around germplasm sharing. The first section of this chapter summarizes the research reported in the previous sections and does not reject either hypothesis.

The first hypothesis given was that restrictions or policies that affect public wheat breeders' costs to access new genetic variation through sharing of germplasm with other wheat breeders' will result in fewer varieties being developed, slower germplasm improvement and a subsequent loss of wheat farmers welfare. The "do not reject" result for this hypothesis is supported in part by the theoretical model. Chapter four shows that as transaction costs increase to share and receive germplasm plant breeders tend to share less which results in a loss of welfare.

The second hypothesis given was that with the adoption of UPOV 1991 the historic patterns of sequential breeding would result in many potential owners of breeding lines creating freedom-to-operate issues. This hypothesis is not rejected as well. The pedigree analysis in chapter 5 shows that many breeding lines from many different sources are used in the creation of CWRS varieties, which provides evidence for the first part of the hypothesis. Also 4 wheat varieties representing approximately 28% of CWRS area were bred using techniques that would allow the varieties to be considered essentially derived from their parents. The PED in UPOV 1991 could allow for multiple ownership of varieties. However, case law study in countries that have adopted UPOV 1991 already show that this provision is used very rarely.

6.2 Conclusion

In the second chapter of the thesis several key points were identified in the literature that set the tone for the rest of the thesis. The practices surrounding plant breeding in Canada have changed from simple conventional methods to sophisticated biotech methods for some crops. The sophistication has spurred private research interests and created a very complex legal structure surrounding biotechnology. It is clear from section 2.3 that any future policy directions weigh the trade-offs between the free rider problem and the freedom to operate problem. Although there are strategies available to firms to ensure FTO in biotech crops probably the strategies that show the greatest potential come from non-profit institutions.

In the third chapter the software development industry and wheat breeding industry are compared. Software and plant variety development are practiced by different entities each with different motivations. Two groups of developers including publicly funded plant breeders' and open source software developers have common motivations. In fact, the wheat variety development system in Canada is a *de facto* open source system. However, the status of the wheat variety development system continuing to be an "open source" type system is in jeopardy. If proposed amendments to the plant breeders'' rights act are realized, in particular the principle of essential derivation, the wheat variety development system could become crippled and variety development would slow. This is a similar conclusion to that of Falcon and Fowler (2002) who also thought that increased ownership and fragmentation of genetic resources will slow variety development.

The results of the fourth chapter can be conveyed in the form of a policy recommendation. Policy decisions that affect the availability and access of research tools and materials need to be examined for their flow through effects. When governments are making policy decisions that affect public plant breeders they need to be cognizant of the fact that policy decisions on public breeders not only affect breeders but they also filter down to the farm level. The model shows that policy choices that increase transaction costs on the crucial interactions between public plant breeders will end up lowering farmer welfare. Policy choices that are perceived to create incentives to innovate among plant breeders (stronger breeder rights) may, in fact, cause the opposite effect and create disincentives for innovation.

The fifth chapter of the thesis shows an in depth analysis of the pedigrees of 14 popular CWRS varieties grown in Western Canada. All of the varieties that were analyzed used at least one registered variety in their creation. Varieties such as AC Superb, Harvest, Infinity, and Prodigy and Journey have a large amount of foreign breeding lines in their pedigrees. AC Abbey, Lillian, CDC Bounty, and CDC Imagine were bred using previous breeding lines almost exclusively from the breeding program which developed the variety. AC Cadillac, AC Barrie, and AC Intrepid were created almost entirely using breeding lines from outside their parent program sources. Finally the varieties CDC Teal and McKenzie do not have a standout class that their sources of genetic variation originate from.

6.3 Study Limitations

The analysis and conclusions drawn to this thesis are mostly applicable to public wheat breeders. Different assumptions in the theoretical model, such as seed costs being greater than zero, profit maximizing for the breeders instead of welfare maximizing, and costs for protecting IP may allow the model to be extended to the private case. If these assumptions were changed, perhaps the model could be used to demonstrate a tradeoff between private breeders sharing and protecting IP.

6.4 Study Extensions

Extending the pedigree analysis to show the value of sharing instead of the amount of sharing would be beneficial and would allow for more conclusive evidence that the theoretical model is correct. If the varieties could be examined in greater detail to show which genetic traits were acquired from a particular breeding line, perhaps a benefit could be attached. For example, if a disease resistant trait was incorporated into an adapted variety that had little resistance there would be an increase in the value of the variety.

A more thorough analysis of international case law regarding UPOV 1991 might better explain the lack of cases regarding essential derivation. Questions such as: Are disputes mostly settled out of court?; Are breeders recognizing this hold up and negotiating with the owners of the parent varieties before breeding?; Are breeding efforts being retarded because of this provision?; perhaps could be addressed if time was spent studying case law.

7 References

________. 2006. "Global Impact of the Plant Genetic Resource Collections Held in Trust by the CGIAR Centres." *CGIAR.* Available at: http://www.sgrp.cgiar.org/InTrustCollections/InTrustCollections_Impact.htm Accessed: April 2007

Astee Flowers v. Danziger Flower Farm. 2005. District Court of the Hague, Netherlands.

Atkinson, R.C, R.N. Beachy, G. Conway, F.A., Cordova, M.A. Fox, K.A. Holbrook, D.F. Klessig, R.L., McCormick, P.M. McPherson, H.R. Rawlings III, R. Rapson, L.N. Vanderhoef, J.D. Wiley, & C.E. Young. **2003**. "Public Sector Collaboration for Agricultural Intellectual Property Management" Science 301(5360):174

Asins, M.J. 2002. "Present and Future of Quantitative Trait Locus Analysis in Plant Breeding." *Plant Breeding* 121:281-291.

Bijman, J. & P.B. Joly. 2001. "Innovation Challenges for the European Agbiotech Industry. *AgBioForum.* 4(1):4-13

Barton, J.H. 2000. "Reforming the Patent System." *Science* 287(5460):1933-1934

Berg, G. & B. Recksiedler. "Frequently Asked Questions: Plant Breeders' Right and the Seeds Act Relating to the Sale of Seed." *Saskatchewan Agriculture and Food* Available at: http://www.agr.gov.sk.ca/docs/production/PBR_and_Seed_Act.asp Accessed: March 2007

Binenbaum, E., C. Nottenurg, P.G. Pardey, B.D. Wright., & P. Zambrano. 2003. "South-North Trade, Intellectual Property Jurisdictions, and Freedom to Operate in Agricultural Research on Staple Crops." *Economic Development and Cultural Change*. 51(2):309-335.

Boettiger, S., G.D. Graff, P.G. Pardey, E. Van Dusen, & B.D. Wright. 2004. "Intellectual Property Rights for Plant Biotechnology: International Aspects" *In* Handbook of Plant Biotechnology. P. Christou & H. Klee. eds. pp 1090-1113. John Wiley & Sons, Ltd., Chichester

Broothearts, W., H.J. Mitchell, B. Weir, S. Kaines, L.M.A Smith, W. Yang, J.E. Mayer, C. Roa-Rodriguez, & R.A. Jefferson. **2005**. "Gene Transfer to Plants by Diverse Species of Bacteria." *Nature* 433:629-633.

Callan, B. & M. Cervantes. 2001. "Managing Intellectual Property Rights From Public Research." Contributed paper, proceedings from the Conference on *intellectual Property and Innovation in the Knowledge-Based Economy.* Toronto, Canada. May 23-24, 2001.

CFIA. 2005. "Proposed Amendments to the Plant Breeders Rights Act to Bring Existing Legislation into Conformity with the 1991 UPOV Convention" Available at: http://www.inspection.gc.ca/english/plaveg/pbrpov/ammende.shtml Accessed: March 13, 2007.

CWB. 2006. "Canadian Wheat Board Variety Survey." Available at: http://www.cwb.ca/public/en/farmers/surveys/variety/2007/

Accessed: April 2007.

DePauw, R.M., T.F. Townley-Smith, G. Humphreys, R.E. Knox, F.R. Clarke, & J.M. Clarke. 2005. "Lillian Hard Red Spring Wheat." *Canadian Journal of Plant Science* 85(2):397-401

D'Aspremont C. & A. Jacquemin. 1988. "Cooperative and Non-cooperative R&D in Duopoly with Spillovers. *The American Economic Review* 78(5):1133-1137

Egelyng, H. 2005. "Evolution of Capacity for Institutionalized Management of Intellectual Property at International Agricultural Research Centers: A Strategic Case Study." *AgBioForum* 8(1):7-17

Falcon W.P. & C. Fowler. 2002. "Carving Up the Commons-Emergence of a New International Regime for Germplasm Development and Transfer." *Food Policy* 27:197-222

Feller J. & B. Fitzgerald. 2000. "A Framework Analysis of the Open Source Software Development Paradigm." Working Paper at University College Cork Ireland.

Gibbons, R. 1992. *Game Theory for Applied Economist.* Princeton NJ: Princeton University Press.

Gray, R. & S. Malla. 2000. "The Economics of CWRS Wheat Research in Western Canada 1961-1998." Saskatoon, Saskatchewan. University of Saskatchewan: Agricultural Economics

Heisey, P.W. & J.P. Brennan. 1991. "An Analytical Model of Farmers' Demand for Replacement Seed." *American Journal of Agricultural Economics* 73(4):1044-1052.

Henderson, R. 1993. "Underinvestment and Incompetence as Responses to Radical Innovation: Evidence From the Photolithographic Alignment Equipment Industry." *RAND Journal of Economics* 24(2):248-270

Herrera-Estrella, L. A. Depicker, M. Van Montagu, & J. Schell. **1983**. "Expression of chemeric genes transferred into plant cells using a Ti plasmid-derived vector." *Nature* 303:209-211.

Hope, J.E. 2004. "Open Source Biotechnology." Ph.D. Thesis. Australian National University.

Humphreys, D.G., T.F. Townley-Smith, R.I.H. McKenzie, & E. Czarnecki. 2001. "AC Corinne Hard Red Spring Wheat." *Canadian Journal of Plant Science* 81:741-743.

Jordens, R. 2002. "UPOV's perspective WIPO-UPOV." *Symposium on the Co-Existence of Patents and Plant Breeders' Rights in the Promotion of Biotechnological Developments.* Geneva, October 25.

Kimpel, J. 1999. "Freedom to Operate: Intellectual Property Protection in Plant Biology and Its Implications for the Conduct of Research." *Annual Review of Phytopathology* 37:29-51

Klein, T.M., E.D. Wolf, R. Wu, & J.C. Sanford. 1987. "High Velocity Micro projectiles for delivering nucleic acids into living cells." *Nature* 327:70-73

Ko, Y. 1992. "An Economic Analysis of Biotechnology Patent Protection." *The Yale Law Journal* 102(3):777-804.

Kremer, M. 1998. "Patent Buyouts: A Mechanism For Encouraging Innovation." *The Quarterly Journal of Economics* 113(4):1137-1167.

Kuyuk, D. 2004. "Stolen Seeds: The privatization of Canada's Agricultural Biodiversity." Sorrento, B.C. Ram's Horn Publishers

Lemley, M.A., & C. Shapiro. 2005. "Probabilistic Patents." *Journal of Economic Perspectives* 19(2):75-98.

Lepage-Monette, A. 2004. "Asked & Answered." *Biotechnology Focus* 7(9):22-24

Lerner, J. & J. Tirole. 2002. "Some Simple Economies of Open Source." *Journal of Industrial Economics* 50(2):212-233

Lesser, W. & M.A. Mutschler. 2004. "Balancing Investment Incentives and Social Benefits when Protecting Plant Varieties: Implementing Initial Variety Systems." *Crop Science* 44:1113-1120

Malla S. & R. Gray. 2003. "Public Research Policy for Today's Agricultural Biotech Research Industry." *Canadian Journal of Agricultural Economics* 51:347-369

Malla S. & R. Gray. 2005. "The Crowding Effects of Basic and Applied Research: A Theoretical and Empirical Analysis of an Agricultural Biotech Industry." *American Journal of Agricultural Economics* 87(2):423-438

McCouch, S. 2004. "Diversifying Selection in Plant Breeding." *PloS Biology* 2(10):e347

Nottenburg, C., P.G. Pardey, & B.D. Wright. 2001. "Addressing Freedom-to-Operate Questions for International Agricultural R&D." *In* The Future of Food. P.G.

Pardey ed,. pp 99-129. Washington, D.C: International Food Policy Research Institute.

Nottenburg, C., P.G. Pardey, & B.D. Wright. 2002. "Accessing Other Peoples Technology for Non-Profit Research." *The Australian Journal of Agricultural and Resource Economics* 46(3):389-417

Noteboom, B. 1999. "Innovation, Learning, and Industrial Organization". *Cambridge Journal of Economics*. 23:127-150

Ordover, J.A., 1991. "A Patent System for Both Diffusion and Exclusion." *The Journal of Economic Perspectives 5(1):43-60.*

Phillips, P.W.B. 2000. "Intellectual Property Rights, Canola, and Public Research in Canada." *In* Agriculture and Intellectual Property Rights.V. Santaniello, R.E. Evenson, D. Zilberman, and G.A. Carlson eds,. pp 223-249. New York: CABI Publishing.

Potrykus, I. 2001. "Golden Rice and Beyond." *Plant Physiology*. 125:1157-1161

Pozniak, C.J. & P.J. Hucl. 2004. "Genetic Analysis of Imidazolinone Resistance in Mutation-Derived Lines of Common Wheat." *Crop Science* 44:23-30

Poyago-Theotoky, J. 1995. "Equilibrium and Optimal Size of a Research Joint Venture in an Oligopoly with Spillovers." *The Journal of Industrial Economics* 43(2): 209-226.

Poyago-Theotoky, J. 1998. "R&D Competition in a Mixed Duopoly under Uncertainty and Easy Imitation." *Journal of Comparative Economics* 26(3) 415-428.

Pray, C.E. & A. Naseem. 2005. "Intellectual Property Rights on Research Tools: Incentives or Barriers to Innovation? Case Studies of Rice Genomics and Plant Transformation Technologies." *AgBioForum* 8(2&3):108-117

Roa-Rodriguez, C. & C. Nottenburg. 2003. "*Agrobacterium* Mediated Transformation of Plants." CAMBIA Intellectual Property Resource. Canberra, Australia.

Rowland, G.G., A.G. McHughen, Y.A. Hormis, & K.Y. Rashid. 2001. "CDC Normandy Flax." *Canadian Journal of Plant Science* 82:425-426.

Sehgal, S. 1996. "IPR Driven Restructuring of the Seed Industry." *Biotechnology and Development Monitor* 29:1821.

Sparnaaij, L.D. & I. Bos. 1993. "Component Analysis of Complex Characters in Plant Breeding." *Euphytica* 70:225-235

Steely, J.A. 2004. "Open Source Software and Resource Sharing." *In* The Changing Landscape for Electronic Resources: Content, Access, Delivery, and Legal issues. Y.S. Fong and S.M. Ward eds. pp 55-70. New York: Haworth Information Press.

Stefansson, B.R. & R.K. Downey. 1995. "Rapeseed." *In* Harvest of Gold: The History of Field Crop Breeding in Canada. A.E. Slinkard and D.R. Knott eds., pp 140-153. Saskatoon: University Extension Press.

Stovin, D.T. & P.W.B. Phillips. **2000**. Establishing Effective Intellectual Property Rights and Reducing Barriers to Entry *In* Canadian Agricultural Biotechnology Research. Paper presented to the 4th International Conference of the International Consortium on Agricultural Biotechnology Research.

Troyer, A.F. & T.R. Rocheford. 2002. "Germplasm Ownership: Related Corn Inbreds." *Crop Science* 42:3-11

Varshney, R.K., A. Graner, & M.E. Sorrells. 2005. "Genomics Assisted Breeding For Crop Improvement." *TRENDS In Plant Science* 10(12):621-630.

Waterhouse, D. 2005. Registrar for Plant Breeders Rights Australia. Personal Communications.

Wright, B.D. **1983.** "The Economics of Invention Incentives: Patents, Prizes, and Research Contracts. *The American Economic Review* 73(4):691-707.

Wright, B.D. & P.G. Pardey. 2006. "The Evolving Rights to Intellectual Property Protection in the Agricultural Biosciences." *International Journal of Technology and Globalization* 2(1/2):12-29.