The Impact of the Plant Breeders' Rights Act on Wheat Productivity: Evidence from Western Canada

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Abstract

Plant Breeders' Rights (PBR) are a form of intellectual property rights enabling breeders of new plant varieties to have the exclusive right to produce and sell propagating material of their new plant varieties. The existence of effective property rights has been pointed to as a stimulus of increased R&D and productivity. Canada has had legislation to provide PBR protection for about two decades, and is considering further strengthening of the regulatory framework. However, there are few studies that have examined the effectiveness of the legislation on crop productivity. This thesis investigates the hypothesis that the adoption of wheat varieties qualifying for Plant Breeders' Rights has increased overall wheat yields and rate of yield increase. The yield response function models are applied to industry data for western Canada and Alberta, respectively. The empirical results show that the PBR Act had a relatively small impact on wheat yields. Among wheat classes, it had a positive impact for Durum wheat in Alberta.

Résumé

Les obtentions végétales sont protégées par un droit de propriété intellectuelle qui donne aux obtenteurs de nouvelles variétés végétales l'exclusivité de la production et de la vente du matériel de multiplication de ces variétés. L'existence des droits de propriété efficaces a été pointue à comme un stimulus d'augmenté R&D et de productivité. Le Canada a eu la législation pour fournir la protection de PBR pour à peu près deux décennies et il considère plus fortifiant du cadre régulateur. Mais peu d'études ont examiné l'efficacité de la législation sur la productivité de récolte. La thèse examine l'hypothèse: l'adoption de variétés de blé qualifiant pour Les obtentions végétales ont augmenté les rendements de blé et le taux d'augmentation de rendement. Les modèles de fonction de réponse de rendement sont appliqués respectivement pour les données d'industrie dans l'ouest du Canada et l'Alberta. Les deux résultats empiriques trouvent que PBR Act a eu le petit impact sur les rendements de blé. Parmi les classes de blé, il a eu un impact positif pour le blé de Durum dans l'Alberta.

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Chapter 1: Introduction

1.1 Background

To encourage investment in research and development (R&D) and other creative endeavors, many countries have institutions to protect intellectual property rights (IPRs). The rationale for protecting IPR is well established and stems from the inability of firms to appropriate the returns of their innovations given the public good nature of knowledge that is embodied in them. While industrial products and processes have been protected via patents, trademarks and copyrights for centuries, the protection of living organisms is a recent phenomenon. For example, it was not until 1930 that asexually propagated plants were first protected as intellectual property in U.S. (through plant patents) and in 1970 protection was extended to sexually propagated plants in U.S. via the Plant Variety Protection Act (PVPA). Perhaps, more significant is the trend in the United States to award utility patents to living organisms ever since the landmark *Chakrabarty v Diamond*[1] ruling that granted a patent on a novel bacterium. The U.S. Patent and Trademark Office now regularly issues patents on novel plant varieties, animal breeds, as well as a host of genetically modified organisms following the decisions of both cases: *ex parte* Hibberd 1985 and *ex parte* Allen 1987[2].

While the U.S. has broadened the scope and subject matter of patentability, most countries including Canada, still do not permit the patenting of living organisms, due to the concerns about the ethics involved in patenting higher life forms. Nevertheless, there was the recognition that R&D investments and efforts of plant breeders in developing novel varieties needed to be rewarded by the granting of

[1] Diamond v. Chakrabarty, 447 U.S. 303, 318 (1980)
[2] *Ex parte* Hibberd, 227 U.S.P.Q.443 (1985); *Ex parte* Allen, 2 U.S.P.Q 2d.1425 (1987)

some form of intellectual property protection. It was with this objective that in 1961 the Union for the Protection of New Varieties of Plant (UPOV) was established and along with the Convention for the Protection of New Varieties of Plants which provided a *sui generic* method for the protection of plant varieties and provided protocols for assessing and describing the unique characteristics of a new variety, ensuring that it is distinct, uniform and stable, the so called DUS criteria. Any new variety that fulfills the DUS criteria is eligible for protection. Most European and OECD countries conform to the UPOV Convention to protect plant varieties but do not allow patent protections (The World Bank, 2006). In recent years, more and more developing countries have introduced or modernized legislation pertaining to plant breeders' rights as a fulfillment for the TRIPS multilateral agreement (Trade-Related Aspects of Intellectual Property) of WTO (World Trade Organization). TRIPS (2002) requires member countries of WTO to implement minimum standards of protection for major types of intellectual property rights.

In Canada, the Plant Breeders' Rights Act (PBR Act) was enacted into law on August 1, 1990. However, its passage was not without controversy as evident by the fact that before its eventual passage, the bill was introduced to the House of Commons three times--in 1980, 1988 and 1989 but failed to come into effect. Much of the opposition to the granting of the PBR Act arose from the ethics of "ownership" of living organisms. Critics warned it would be a precedent-setting case to allow life ownership and would open doors to full patent rights on the other forms of life. Other concerns included the monopoly control by private firms over plants that would lead to higher seed prices for farmers and higher food prices for consumers. Moreover, people were afraid that multinational companies that had the capital to conduct R&D would eventually control seeds and genetic resources thereby putting farmers and consumers at a disadvantage (The Ottawa Citizen, 1989). Some groups such as the Canadian Environmental Law Association (CELA) expressed concerns and predicted pesticide manufacturers would sell varieties tailored to certain chemicals and that could lead to an "environmentally damaging" agriculture system and consequently undermine efforts to increase organic farming in Canada (The Ottawa Citizen, 1989).

Proponents of the PBR Act argued that it was a necessary tool to encourage innovation as it would allow breeders the opportunity to collect royalties on the seeds they develop by giving them the necessary incentive to undertake more R&D. It was felt that a larger amount of private R&D would complement that of the public institutions and provide more research that would lead to the development of new and better plant varieties benefiting farmers and consumers (The Windsor Star, 1988). In addition, it was argued that the PBR Act would place Canadian plant breeders on an equal footing with other major competitors such as the United States who had access to such protection. Advocates of the legislation indicated the PBR Act could promote Canadian cultivars in foreign countries and thus enable greater in-bound and out-bound technology transfer and commercialization of new plant varieties (Downey, 1977). Other benefits such as encouraging the development of joint ventures and stimulating cooperation in the plant breeding industry have also been suggested.

Under the Canadian PBR Act that was eventually passed in 1990, there are four criteria or bases for granting property rights to novel plant varieties. First, the varieties must be new in the sense that they have never been commercially planted in Canada prior to application. Second, the variety must be distinct or different from all other varieties on the market. Third, the variety must be uniform such that the variation from variety to variety must be predictable and can be described by the breeder. Finally, the variety must be stable; that is, remain true to description from generation to generation (Canadian Food Inspection Agency, 2006b).

Once rights are granted on a particular variety, the breeder and/or owner has legal control over the variety and other propagating material for a duration of 18 years. During the protected period the owners may charge a royalty for the propagation and sale of the protected variety and take legal action against individuals that are unauthorized to commercialize the variety. But the scope of protection provided by the PBR Act is not as broad as that of patents. There are two notable differences. First, under the PBR Act, a "farmer's exemption" allows growers to save and use the protected seed varieties without infringing on the holders' rights. The PBR Act placed limited or no restrictions on the use of the harvested product resulting from the sowing of the protected seed variety. Secondly, a "research exemption" allows for breeder and researchers to use the protected varieties for the purposes of developing new plant varieties or research on them. It is based on the recognition that further breeding necessitates the physical use of existing plant varieties as an intermediate input in further varietal development (Eaton, 2006).

Did the PBR Act achieve its intended goals? To answer this basic question and as part of the requirements of the Act, the Canada Food Inspection Agency (CFIA)—the federal agency responsible for implementing the Act—was mandated to review the impacts of the PBR Act after a ten years' period. The CFIA review, published in 2001, was generally positive of the impacts that the PBR Act was having by pointing out that the private sector had increased its investment by over 100%, the public sector was benefiting through receipts of royalties that were re-invested into R&D, access to foreign varieties by growers had improved, and the development of improved varieties had increased.

1.2 Statement of Problem

While the PBR Act was viewed by the CFIA as having a positive impact, the results need to be interpreted with some caution. First, the methodology employed by the CFIA was qualitative in nature and solicited the expert opinions of plant breeders, researchers, seed traders, farmers, nurserymen, industry organizations and government agencies. Most information was from in-person and telephone interviews from the various stakeholders and we know that consulting information could be subjective and thereby relying on it could reduce the reliability of the results. Additionally, without quantitative analysis, the results would not be rigorous enough to reflect the real impact. Even if the interviewees' opinions were expressed objectively, 76 people from all aspects of horticulture and agriculture industry is not enough to make the sample unbiased.

A case in point is how the CFIA review evaluated the impact of the PBR Act on crop productivity. The report found that there had been significant productivity gains made in the agriculture industry as measured by increase in yield and expansion in area, but the analysis only compared the difference in the yield and area data for the years 1990 and 2000. Using this approach, the report found that for wheat, there was a 22% increase in yield of which 60 to 75% was attributed to PBR Act based on the estimates of the expert opinions of the breeders that were consulted. A number of difficulties arise with using this approach. First by only looking at the difference between 1990 and 2000, the analysis ignores any trends in the data which could be more suggestive. Second, the analysis does not control for other variables, such as improvements in agronomic factors. Third, by using expert opinions to attribute the yield gain to PBR, the analysis is influenced by individual biases that may not be reflective of the actual impact. It is impossible to determine whether yields in other years during the ten year period were increasing all the time or were fluctuating. Without detailed and precise analysis, this finding is inconclusive. Overall, the CFIA review provides no quantitative analysis to support the claims of the experts.

The argument for the PBR Act is to provide the necessary incentives for the development of novel crop varieties which are "better" than the available varieties and which eventually will lead to commercialization and widespread adoption. One might hypothesize that the protected varieties would result in higher yields over time, since farmers would grow more protected (and productive) varieties to increase profits. Plant breeders and seed companies would also benefit from higher sales of their protected varieties and would re-invest their profits into further varietal development resulting in ever more improved varieties. To consider this possibility, this thesis tests this basis hypothesis for the case of wheat. Wheat is one of the major cereal crops for export and for domestic consumption in Canada and relies heavily on PBR certificates for intellectual property protection. Since wheat is an open-pollinated crop, PBRs are an important tool for breeders to appropriate the returns of their research effort.

To understand what impact the PBR Act has had on the wheat economy, Figures 1 and 2, show the annual yields before and after 1994, while Figure 3 shows the harvested area for the past forty years for the major wheat classes in Canada. If the PBR Act was effective, one might expect yield and area trend to increase after 1994 when the new protected varieties were available to growers for commercial use.

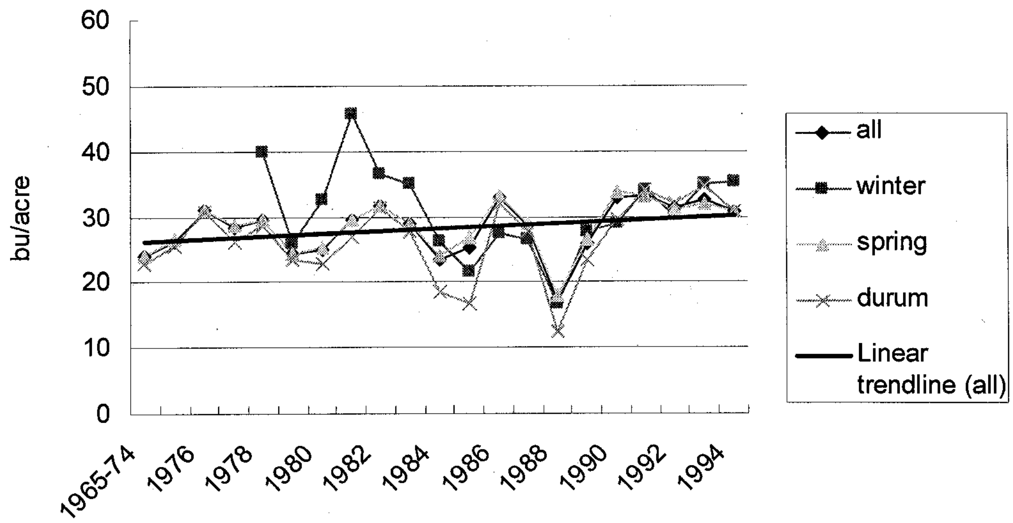

Figure 1: Annual Wheat Yields in Western Canada (1965-1994)
Source: Statistics Canada (1965-1994)

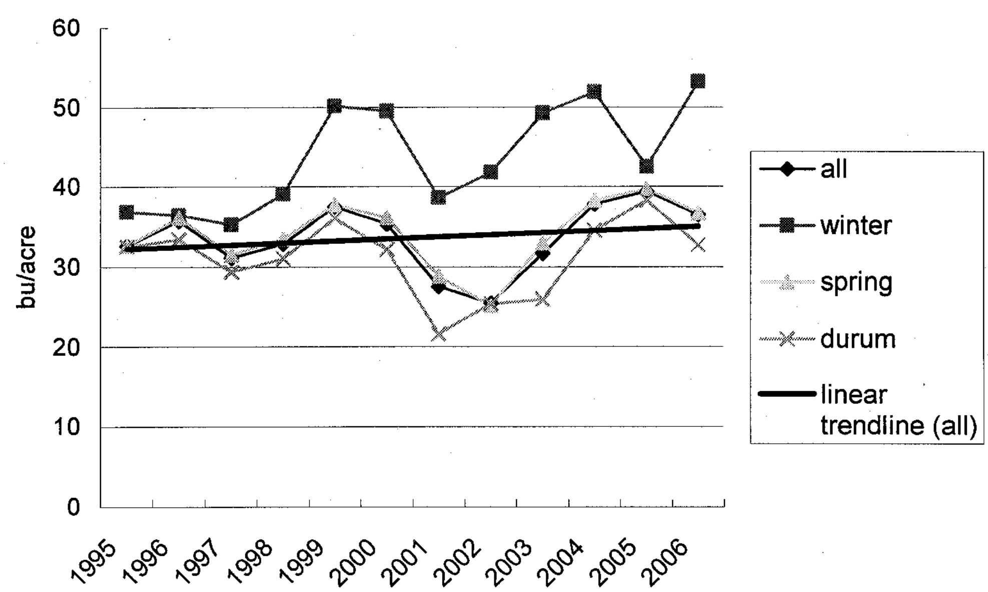

Figure 2: Annual Wheat Yields in Western Canada (1994-2006)
Source: Statistics Canada (1994-2006)

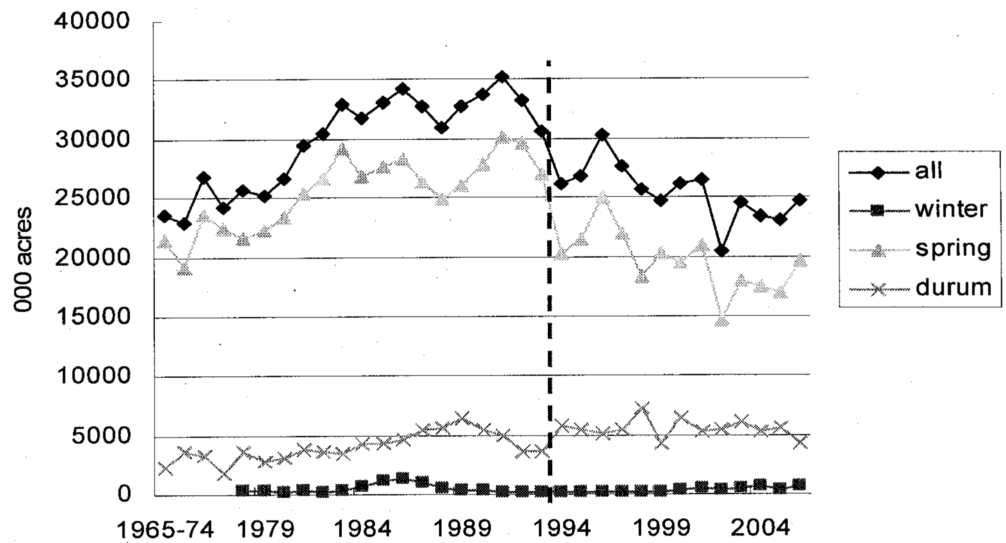

Figure 3: Annual Harvest Area of Wheat in Western Canada (1965-2006)
Source: Statistics Canada (1965-2006)

According to Figure 1 and 2, there is no clear difference between the slopes of the trend lines of all wheat before and after 1994. Both slopes are positive but small, suggesting there has not been much yield shift as indicated from the PBR review of CFIA. Nevertheless, the yield gaps between winter wheat and other classes of wheat increased after 1994. However, without controlling for other factors, it is still unknown whether this yield gap is attributed to the PBR Act or not. On the other hand, if the PBR Act had a positive impact, we would expect an expansion of wheat area along with the increased yield. However, from Figure 3, wheat harvest area declined in the early 1990s and continued to decline until recently, primarily impacted by the reduced market opportunities.

It is evident from examining the trends in Figures 1, 2 and 3 that there was no dramatic shift in the productivity of wheat since the protected varieties became available to producers in 1994. There could be a number of reasons. First, the PBR Act did not induce much incentive for R&D investment so that the few new varieties available for use are not higher yielding. Second, even though our Figures show that there was not a dramatic shift in wheat productivity, the PBR Act could still have an effect as we are not controlling for other factors (e.g., agronomic improvements).

To explore whether the productivity performance of wheat since the PBR Act was enacted is due simply to a lack of protected varieties available, Figure 4 highlights the trend in PBR applications and certificates issued for wheat. Canada began to accept wheat PBR applications in 1992 and the first right was granted in 1993. Agricultural crops that have been granted Plant Breeders' Rights in Canada are concentrated in cereal crops including wheat, barley, corn and oats; oilseeds including canola, soybeans and flax; and pulse crops including peas and beans. Oilseeds account for more than 60% of total agriculture applications while cereals comprise for about 23% (Canadian Food Inspection Agency, 2006a). During 1992 to 2006, there were 102 wheat PBR applications and 52 applicants were granted PBR rights. Both applications and rights granted are increasing.

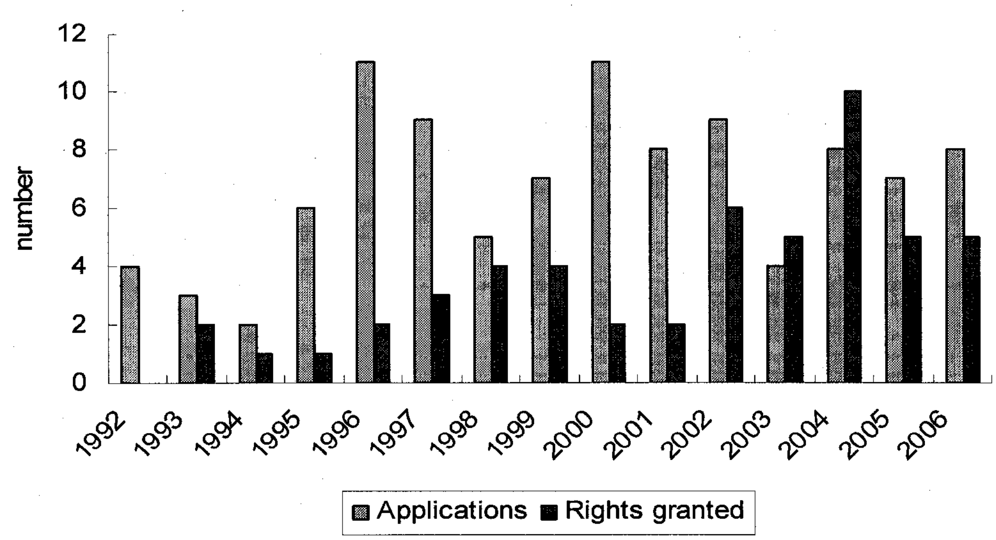

Figure 4: PBR Applications and Rights Granted for Wheat (1992-2006)
Source: Canada Food Inspection Agency PBR office (2006a)

Figure 5 shows the number of wheat varieties planted in western Canada from 1998-2006 and the corresponding number of PBR wheat varieties. Both the total number of wheat varieties and PBR varieties has trended upward. In 1998, the PBR varieties comprised only 20% of all varieties while in 2006 they comprised of 48%. It seems that more and more protected varieties were planted in western Canada. If protected varieties were more productive and more of them were planted, the yields would be expected to trend upward as well. However, the yields did not follow the upward trend. It increased at the beginning and decreased later and then increased again. Even if PBR varieties were more productive, it is very likely that other factors such as climatic conditions and improvements in agronomic practices may have influenced yields. Without accounting for these factors, the effect of the PBR Act on wheat productivity is unclear.

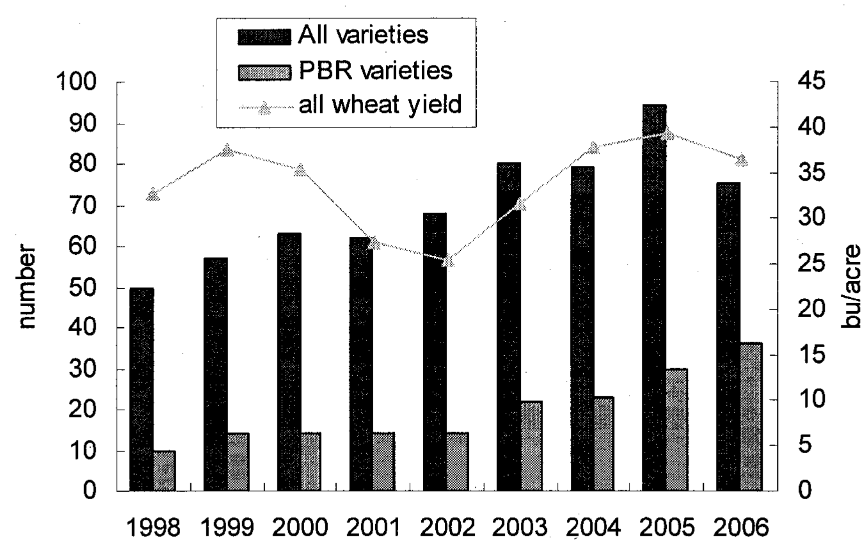

Figure 5: Number of All and PBR Wheat Varieties Planted in Western Canada (1998-2006)
Source: Canadian Wheat Board (1998-2006), Statistics Canada (1998-2006)

Western Canada is the major wheat-producing area in Canada and it accounts for 97% of all wheat planted in Canada. There are eight classes of wheat grown in Canada: Western Red Spring, Western Red Winter, Western Extra Strong, Prairie Spring Red, Prairie Spring White, Amber Durum, Soft White Spring and Hard White Spring (Canadian Grain Commission. 2007). Figure 6 illustrates the acreage share of PBR varieties for eight wheat classes in western Canada. From the Figure, it is apparent that no Soft White Spring wheat varieties had varieties that were protected by Plant Breeders' Rights, while Western Extra Strong and Western Red Winter began to have varieties qualifying for PBR only in recent years. For the rest of the wheat classes, the acreage share of PBR varieties shows an upward trend. Whether this trend was due to more protected varieties planted or protected varieties seeded to a larger area, the PBR Act does seem to have a positive impact on the availability of new varieties.

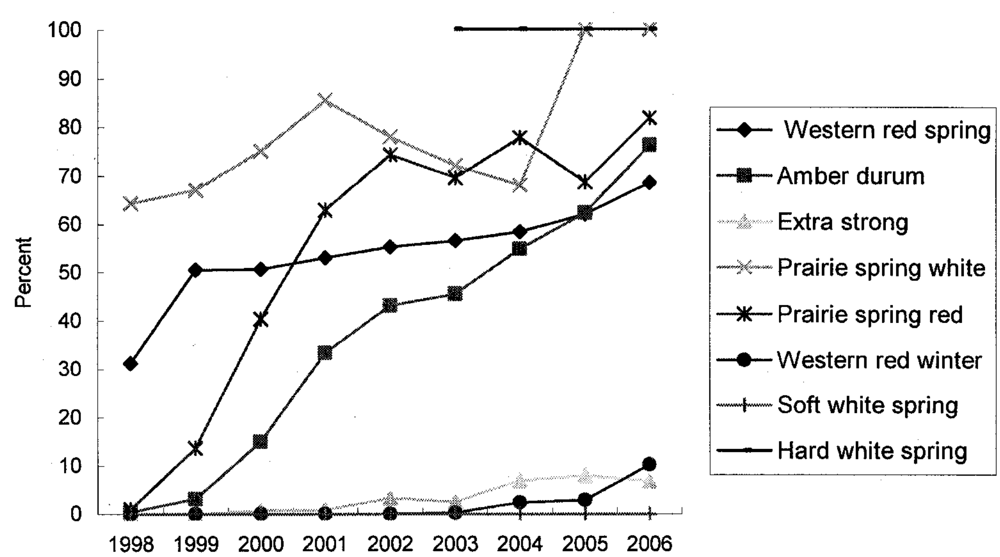

Figure 6: Share of Acreage of PBR Varieties by Class in Western Canada (1998-2006)
Source: Canadian Wheat Board (1998-2006),
Canadian Food Inspection Agency PBR Office (2006a)

1.3 Objective and Hypotheses

The above analysis reveals that the impact of PBR on wheat productivity is at best ambiguous rather than positive which was the conclusion reached by the CFIA. It remains unknown whether the PBR Act has led to superior varieties or just to a proliferation of varieties that differ in little more than name. Wheat is an open-pollinated crop and the genotypes of open-pollinated varieties remain virtually unchanged across generations, so growers can purchase seeds in one year and replant the seeds from the previous harvest. In this way, breeders receive only partial royalties, which may reduce the incentives to invest (Venner, 1997). Therefore there is need to find econometric evidence to quantify the relationship between the PBR Act and wheat productivity and to ascertain what effect the PBR Act had on wheat productivity improvements. Meanwhile, since the Canadian PBR Act adheres to the terms of the 1978 UPOV Convention, different interest groups (the PBR office, seed industry, and representatives from horticulture and agriculture industries) are trying to bring the Act in compliance with the latest 1991 UPOV Convention in order to further strengthen the intellectual property protection. Hence, a better understanding of the economic effect of the PBR Act will help policy makers and related interest groups to improve the design of the PBR regime in Canada, which will consequently benefit society and foster large investments in R&D.

Therefore, the objective of this research is to examine the effects of the PBR Act on wheat productivity improvement: to evaluate the impact of the PBR Act on wheat yields and to estimate the different effects of the PBR Act across different classes of wheat.

Based on the above analysis, the hypotheses of the study are 1) the adoption of wheat varieties qualifying for Plant Breeders' Rights has increased overall wheat yields and the rate of yield increase; 2) the PBR Act has different impacts on different wheat classes as the breeders' market size varies between these classes.

1.4 Study structure

In the next chapter, we are going to briefly review studies on the impact of IPRs (Patents, etc) on productivity and economic growth. This is followed by a comprehensive review of studies on the impact of PBR from different perspectives: R&D investment, productivity, international technology transfer, distribution of benefits and industry structure. Next, we will examine specific PBR wheat studies and highlight current controversies surrounding PBR and identify research gaps.

For the data and methodology part, first we describe the data used to analyze the yield trends and patterns of adoption of wheat varieties. Based on previous studies about the determinants of crop yield, we will develop the conceptual framework of yield response functions and respective empirical models for western Canada and Alberta.

With regard to the empirical analysis, first we will examine the econometric evidence of the relationship between provincial wheat yields and PBR Act in western Canada. Then, we investigate the econometric evidence of the relationship between wheat variety yields and PBR Act for different wheat classes in Alberta. Finally, study conclusions are summarized, discussing limitations and policy implications and suggestions for future research.

Chapter 2 Literature Review

2.1 Introduction

This chapter provides an overview of the economic argument for intellectual property rights (IPRs) followed by a review of studies that seek to assess the impact of IPRs on productivity and economic growth. The majority of studies that have evaluated the impacts of IPRs, have focused primarily on patents because of their long history, predominance and the richness of patent data which easily lends itself to empirical analysis. It is only in recent years that there has been a movement to analyse the impact of Plant Breeders' Rights (PBR) as well as to address a number of other issues related to IPRs. These include the role of PBR in encouraging investment in research and development (R&D), enhancing productivity, promoting international technology transfer, as well as their implication for industry structure and performance. This chapter also reviews some of the PBR impact studies with a view towards understanding the effectiveness of PBR regimes in meeting their stated goals and identifying research gaps in the literature. Special attention will be given to review Canada's specific PBR studies and those related to breeding innovations on wheat, which is the focus of this study.

2.2 The Economic Rationale of Intellectual Property Rights

Intellectual property rights (IPRs) give the inventors or owners the legally enforceable power to prevent others from using an intellectual creation or to set the terms on which it can be used. In most developed countries, the protection of IPRs is now a part of the institutional infrastructure that is meant to encourage private investments in R&D and create other policy inventives. Throughout history, different legal instruments of intellectual property protection have emerged.

Patents, trademarks, copyrights and neighboring rights are the traditional forms of IPRs, while ongoing technological change and unique characteristics of certain industries have led to additional forms of protection, such as the *sui generis* systems for the protection of integrated computer circuits, database and plant varieties. Although stronger protection of IPRs implies trade-offs for a society: the increased market power of IPR holders versus the additional incentives in R&D and foreign direct investment (FDI), IPRs are widely regarded as raising social welfare and are an important tool in economic policymaking (Braga et al. 2000). IPRs have three interrelated economic roles, namely to provide incentives for innovators, to encourage technology transfer, and to improve societal welfare through the provision of improved products and services.

2.2.1 IPRs as an Incentive Mechanism

A free market economy characterized with decentralized decision making, prices and private property rights can lead to efficient production and distribution of goods and services, yet may fail to maximize social benefits if non rival, partially excludable goods exists in the market (Venner, 1997). Public goods have both nonrival and nonexcludable characteristics[1]. Intellectual inventions or creations have some characteristics of public goods so the cost of reproduction of intellectual creation is typically a fraction of the cost of production, which means that little revenue will be collected and this will curtail the incentive for investment in research. By granting temporary exclusive rights, IPRs are intended to allow inventors or owners to set the price above marginal cost to recoup investment costs incurred in the development of intellectual creation. In this context, IPRs can serve as a second-best optimal solution to the problems created by public goods characteristics of knowledge. IPRs could be set such that they stimulate the

[1] A public good can be enjoyed by numerous individuals at the same time (nonrival); once a public good is available, denying access to a consumer is prohibitively expensive (nonexcludable). (Byrns & Stone, 1992)

development of new products and production processes at a socially optimal rate.

Intellectual Property Rights, especially patents, are considered to play an important role in the creation of new knowledge and information as they require the details of invention to be disclosed so they can be replicated, which permits follow-on innovation. Thus, the economic logic of granting patent protection to the inventor is straightforward. If there were no incentives for inventors, it is likely that fewer innovations would be developed thereby retarding economic progress (Jaffe and Lerner, 2004). While the incentives provided by patents can be strong, empirical evidence suggests that the incentives can vary across industries. For certain industries, such as pharmaceutical and biotechnology, the use of patents is widespread and particular importance is attached to patent protection, with patents playing an important role in the innovation process (Taylor and Silberston, 1973; Mansfield, 1986; Levin et al. 1987). However, most industries do not find patents to be a particularly effective means of appropriating returns from R&D (Braga et al., 2000). This may be due to the particular characteristic of pharmaceutical and biotechnology products. Once developed, the compounds can be easily imitated in the initial stages of the long product cycle unless they are legally protected by patents.

Sometimes, the movement toward stronger patent protection may restrict the innovation process rather than stimulate technological and economic progress as researchers find it difficult to further enhance a technology without infringing upon the rights of patent holders and consequently lowering R&D investment (Mazzoleni and Nelson, 1998). Similarly, a term "tragedy of the anti-commons" was coined by Heller (1998) which explained a situation where rational individuals collectively waste a given resource by underutilizing it. Heller and Eisenberg (1998) pointed to this situation in biomedical research as the proliferation of IPRs blocks further technology development and prevents useful and affordable products from reaching the marketplace thereby contributing to the under utilization of scarce resources.

2.2.2 IPRs as a Technology Transfer Tool

David (1993, page 1961) pointed out that "IPRs can play a positive role in diffusion of knowledge and information". Perhaps a key trade-off with patents is that patents are granted in exchange for the publication of the patent claim. In exchange for temporary exclusive rights, the owners have an incentive to disclose the details of the invention to the public so that anyone can use the information from the patent to further develop innovations. Once they expire or are abandoned, the intellectual creation becomes part of the public domain. Moreover, there is evidence from some studies that patents do not effectively deter imitation by rivals for very long, which means others can use the information to further develop innovations in the short term (Mansfield 1986; Levin et al. 1987).

Internationally, information and technology is diffused through various channels such as trade, Foreign Direct Investment (FDI), international licensing agreements and technical assistance. For example, a study by Mansfield (1994) showed that IPRs affect FDI decisions by inducing more FDI that results in higher knowledge spillovers from foreign to domestic markets. Other studies have generally found IPRs to have a positive effect on economic growth (Rapp and Rozek, 1990; Gould and Gruben, 1996). Another element regarding the role of IPRs in the international diffusion of knowledge is the way in which protection affects the vertical integration of multinational firms. Surveys have found the IPRs regime of the host country to be highly relevant for decisions to invest in R&D, moderately important for FDI in manufacturing and of limited relevance for investments in sales and distribution outlets (Braga et al. 2000).

2.2.3. IPRs and Social Welfare

It is suggested that stronger protection of IPRs implies trade-offs for the economy with the potential effect of increased market power for IPR holders that ought to be weighted against the benefits obtained through the additional incentives. In this context, one could expect IPR holders to reduce output or sales to support the higher monopolistic prices. In some IPR-sensitive industries, such as the pharmaceutical industry, the IPR impact on prices is apparent. Redwood (1994) studied the potential impact of product patents on prices in India and found there was a positive range of price increased from 9 to 76% depending on various assumptions on market demand.

Upon the introduction of Plant Breeders' Rights protection, the concern of many countries has been the possibility of price increases for new plant varieties. Several studies have examined the price effect of IPRs. Lesser (1994) used a hedonic pricing model to examine the marginal price with Plant Variety Protection (PVP) certificates for soybeans and found the certification contributed only 2.3% to price suggesting the monopoly rents were small. Hu et al. (2006) used a system model to study the impact of PVP on rice seed prices in China with the seed price of PVP varieties increasing by only 0.84 Yuan/kg. Both of their findings show prices have been affected slightly.

Considering the trade off of IPRs for social welfare, one could support Stiglitz's (1999, page 11) claim that "it is possible that an excessively strong intellectual property regime may actually inhibit the pace of innovation". Consequently, concentrated holdings of patents by firms can block market entry and slow the pace of economic development. Nevertheless, this is not always the case. Patent protections do not prevent competitors or affect imitators from entering the market (Mansfield, 1986; Levin et al. 1987). Moreover, Baumol (2002) found that competition in a free market is to be regarded as the main cause for economic growth as 80% of the economic benefits generated by innovations do not accrue to the parties directly or indirectly involved with the innovation.

2.3 The Impact of IPRs on Economic Growth and Productivity

Innovation is at the heart of growth models and drives long-run productivity and economic growth (Khan and Luintel, 2006). This subsection will primarily examine the economic implications of IPRs (mostly patents) on productivity and economic growth.

2.3.1 IPRs and R&D Investment

Evidence shows that the social return to R&D investments are higher than the private returns (Griliches, 1984; Mairesse and Sassenou, 1989; Evenson, 1989; Alston et al., 2000). Since induced innovation is necessary for long term economic growth, several studies have sought to understand the relationship between IPRs (primarily patents) and a firm's decision to invest in R&D. In these studies, patents play a role in stimulating investment for certain industries such as pharmaceutical, chemical and biotechnology industries (Taylor and Silberston 1973, Levin et al. 1987; Greif, 1987). However, in most other industries this is not the case. Mansfield (1986) conducted an empirical study on a random sample of 100 U.S. manufacturing firms and found the patent system seemed to have a relatively small effect on R&D in most industries except pharmaceuticals and chemicals. Two studies in Canada for different periods also found that patents were not so important in innovation. Firestone (1971) concluded that patents were not playing a big role on the decision to invest in a Canadian subsidiary. Baldwin et. al (2002) found the relationship between innovation and patent use was much stronger going from innovation to patent use than from patent use to innovation as firms and industries that made more intensive use of patents did not tend to produce more innovations. In selected studies from several countries (U.S, Japan India and Europe), the findings were not very different from the above studies (Mazzoleni and Nelson, 1998; Luthria, 1996). However, in a more recent study by Kanwar and Evenson (2003), they used cross-country panel data from 1981-1995 to examine the strength of IPRs on innovation and technological change in developing countries and their evidence shows that IPRs had a strong positive effect on R&D investment expenditures at the economy-wide level.

Empirical studies about the relationship of IPRs and R&D investment in developing countries are relatively few and their approach appears to be narrowly focused. In Brazil, a study examined the role of stronger IPRs and found most firms would invest more in internal company research and would improve training for their employees if better legal protection were available (Sherwood, 1990). In most cases, studies emphasized the inventive effect of IPRs on agricultural R&D investment. Dahab (1986) and Mikkelsen (1984) conducted studies of the agricultural implements industry respectively in Brazil and Philippines and found the utility model[1] (or petty patents) stimulated adaptive inventions in these countries. However, Wijk (1995) studied the impact of PBR on R&D in Argentina and showed PBR protection seemed to have prevented the decline in R&D for soybean and wheat rather than having stimulated additional R&D expenditure. Moreover, Louwaars et al. (2005) found no strong empirical evidence from the five case study countries that PBR protection had stimulated innovation activities.

In sum, the evidence on the incentive effect of IPRs on R&D is mixed. While R&D is shown to be a highly profitable venture (as shown by the high rates of returns), the incentive effect of IPRs is highly variable across industries. This implies that

[1] Utility models differ from utility patents in three ways: a. they are of shorter duration(4 to 7 years typically); b. they are seldom examined; c. there is little or no inventive step required (Lesser, 1990).

R&D may not be an accurate indicator of the impact of IPRs as other factors and trends influencing R&D decisions. For biological based R&D such as plant breeding, the difficulty of having a proper before-and-after study due to the long timeframes of plant breeding and other important developments such as advances in modern biotechnology may considerably shift the trend line of R&D (Lesser, 1997).

2.3.2 IPRs and Economic Growth

In most popular growth models innovation is carried out to make profits on the introduction of new products. In the process of new product development, the accumulation of human capital lowers the cost of innovations. The pace of economic growth increases with larger stocks of human capital. Thus, by creating an environment conducive to the accumulation of human knowledge, IPRs will tend to increase innovation, productivity and economic growth (Gould and Gruben, 1996).

The role of IPRs in long-run productivity and economic growth has been examined by Gould and Gruben (1996) who found that stronger IPRs corresponded to higher economic growth rates in a cross-country sample; a result attributed to the role of IPRs in fostering R&D investments. Their findings suggested the linkage between IPRs and innovation may play a weaker role in less competitive, highly protected markets. Park and Ginarte (1997) examined how patent protections affected long-run economic growth and found that stronger IPRs have the potential to improve economic growth. But their key finding is that stronger IPRs will not contribute to growth directly (by being codified into laws), but indirectly by making more investment activities possible, particularly R&D activities. Moreover, from their 60 cross-country samples, they found R&D was an important determinant of growth rate in both developed and developing countries, while IPR impact for the R&D activities of the developed countries but not for the less developed countries. In a recent study, Kwan and Lai (2003) examined the impact of IPRs on growth by using an expanding-variety type R&D-based endogenous growth model and found that a tightening of IPRs caused a fall in consumption and the expansion of R&D investment which led to higher growth of consumption following the initial drop. Furthermore, they were able to compute the optimal level of IPR by taking into account transitional dynamics.

According to the studies reviewed on the relationship between IPRs and productivity growth, a consensus emerges to suggest that IPRs do have an important role in sustaining long run productivity and growth. Moreover, Park and Ginarte (1997) showed that IPRs impact growth by fostering R&D investment and making R&D investment activities possible. With regard to the relationship between R&D investment and productivity, a number of empirical studies found that R&D investment contributed to domestic productivity by focusing on the manufacturing sector and analyzing firm and industry level cross-sectional data (Mansfield, 1988; Griliches and Mairesse, 1990; Hall and Mairesse, 1995). Their findings report statistically significant R&D elasticities ranging from 0.1 to 0.2.

2.4 The Economic Impacts of Plant Breeders' Rights

Much of the economics literature on IPRs has focused on the relationship between patents and productivity growth. It is only in recent years that attention has been paid to understanding the impact of other forms of IPRs and the specific role they play in fostering the innovation process. In this subsection we review the literature on the impact of Plant Breeder's Rights (PBR) in different countries. Many of the studies have concentrated on the United States where IPRs for plant based and other biological organisms have been available for a greater period of time. For example, plant protection in the United States for asexually propagated plants has been available since 1930; for sexually propagated plants in the form of Plant Variety Protection (PVP) since 1970 and since 1980 the landmark case of *Chakrabarty v Diamond* has provided utility patents for living organisms.

Globally, UPOV[1] provides a framework for intellectual property protection of plant varieties, and the number of countries that grant such rights has grown over the years. Furthermore, the types of inventions that can be protected has expanded and the scope of protection has been broadened (The World Bank, 2006).

2.4.1 Impact of Plant Breeders' Rights on R&D Investment

Does PBR stimulate R&D investment and breeding research? Like patents and copyrights for the protection of industrial inventions, PBR are a second best solution for promoting innovation in the agricultural sector. Like patents which are intended to stimulate R&D investments, the positive effect expected from PBR is to increase R&D by plant breeders for the purposes of developing improved agricultural plant varieties. Most empirical work on the R&D effects of IPR for plant varieties has been undertaken in the United States and Spain and the amount of international research is quite limited. Studies that have examined the effect of PBR on R&D inputs in the breeding sector have focused on the R&D expenditures, the number of research programs, investment in human resources and output in terms of certificates granted for plant varieties.

Butler and Marion (1985) used survey information and data on certificates to examine changes in breeders' behavior after the U.S. PVPA was passed in 1970. They found that R&D investments by seed companies increased most rapidly in the period leading up to the Act (possibly in anticipation). There is evidence of

[1] UPOV (the Union for the protection of New Varieties of Plants) was established by the International Convention for the Protection of New Varieties of Plants. The objective of the Convention is the protection of new varieties of plants by an intellectual property rights.

increased investment in a few specific crops (shifted away from corn and toward soybeans) and the number of soybean and wheat crop varieties released in the 1970s increased sharply. Their study shows that the PVPA has had a positive effect on private plant breeding R&D for soybeans and wheat. Perrin et al. (1983) surveyed seed companies for data on R&D expenditures and found that the PVPA has had a positive impact on private research for non-hybrid crops (soybeans and cereals). Several studies surveyed investments in financial and human resource (scientists) for plant breeding in U.S. (Kalton and Richardson 1983; Kalton et al. 1989; Frey, 1996), although they did not seek to directly link the changes to the PVPA. Venner (1997) analyzed both trends in public and private investments in wheat breeding in the United States and found private investments remained relatively static while public investments on wheat breeding actually increased over the 1970-1993 period. In sum, these studies indicated that private sector breeding has increased following the PVPA in a limited number of crops.

Studies in other countries have also found ambiguous effects of PBR on plant breeding investment. Wijk (1995) reported the PBR impact in Argentina and found PBR protection prevented the reduction in R&D expenditure for soybean and wheat rather than having stimulated additional R&D. Moreover, from their findings, the increase in R&D expenditure by multinational seed companies seems not related to PBR enforcement but rather from the incentive of changes in economic policies. However, Diez (2002) examined the impact of PBR in Spain and found that PBR had a positive incentive for private sectors to have increased its market share because of higher appropriability conditions. In Canada, there had been almost a three-fold increase in investment in the private sector in both horticulture and agriculture industries since the passage of PBR and the public sector were able to partially fund their plant breeding programs from the royalties earned from seed sales (CFIA, 2001).

It seems that PBR did have some effects in agricultural and breeding research in both industrialized and developing countries, however, the effectiveness of PBR was still inconclusive. One possible explanation is that it is difficult to draw firm conclusions on the effect of PBR because of other factors (such as market developments and other policies) influencing R&D decisions. Lesser (1997) pointed out the difficulty of having a proper before-and-after study was due to the long time it takes to develop new crop varieties.

2.4.2 Impacts on Output and Productivity

From a policy and social welfare perspective, it may be more important that the PBR Act has a positive impact on the outputs of R&D, such as a more productive variety or a variety with enhanced quality attributes. Lesser (1997) points out that whether PBR legislation leads to improved varieties or only cosmetically improved ones is an unanswered question.

Although the most common measure of productivity in agriculture is yield (output per unit of land), improved varieties could also be input or cost saving (for example, herbicide tolerant crops and better pest resistant crops that save on labor) and quality enhancing (for example, crops with higher nutritional content). Since useful data on these aspects except yield is limited, previous studies examined the effect of PBR on crop yields for different kinds of crops.

Perrin et al. (1983) examined the yields of soybean varieties in yield test plots in North Carolina, Iowa and Louisiana. By testing the trend in variety improvement and examining the effects of whether the variety was released before or after 1970 on the yields observed, they found a positive trend of 0.12 bu/acre per year improvement after 1970, yet this trend is significant only at a 16 percent level of significance. However, Lesser (1997) argued that this is a fairly weak test because of the limited number of protected varieties and suggested such analysis should be repeated with more recent and comprehensive data. Babcock and Foster (1991) measured the impact of PVP to flue-cured tobacco yield in North Carolina from 1954-1987 using a time index variable to separate genetic and nongenetic influences on yield and found no evidence that the PVPA had discernable effect on the development of higher yielding flue-cured tobacco varieties. Alston and Venner (2002) tested the effects of the PVPA on commercial wheat yields and experimental wheat yields for a number of states. They found that the PVPA had no statistically significant effect on both commercial and experimental wheat yields. For the case of Canada, Carew and Devadoss (2003) quantified the contribution of PBR to canola yields in the province of Manitoba and their results revealed that PBR had a positive and statistically significant effect on canola yields. Another positive result was found by Naseem et al. (2005), who investigated the effect of PVP varieties on cotton yields in the U.S. and they found that there has been an increase in the number of new varieties released annually since the PVPA and their econometric evidence indicated that PVP had an overall positive effect on cotton yields.

The evidence from these studies were inconclusive in terms of contributions to agricultural productivity from IPR for plant variety protection. Since most of these studies were from the United States, there is need to replicate these kinds of studies for more crops. On the other hand, it is difficult to hypothesize why the results measuring the effects of PVPA on crop yields differed between these studies. One possible reason is that among the studies investigated, researchers employed different crop types, data sources and estimation methods.

2.4.3 Impacts on International Technology Transfer

Like patents which have a positive effect on the diffusion of knowledge and information, the implementation of PBR laws is also expected to create the incentive to promote technology transfer and knowledge spillover. If PBR does facilitate the transfer of plant varieties between countries, there would be significant flows of varieties across countries. However, empirical studies on the economic impacts of PBR to facilitate the transfer of technology and international diffusion have been quite limited.

The only available empirical study in this area is from Srinivasan (2004) and he examined the transferability effect of PVP in facilitating the flow of varieties across countries by three ways: transfer of protected varieties by crop across UPOV member countries, foreigners' share of PVP certificates and determinants of foreign participation in PVP. He found that the strength of a IPR regime significantly influences PVP grants but the transferability effect of PVP across countries (mostly developed countries) has been limited. The determinants of foreigners' participation in a PVP system showed that it was not only influenced by the strength of IPRs, but also by other factors (for example, the size of market and openness of the economy). Moreover, most transfers of protected varieties have been within a limited number of EU countries and have been facilitated by special features of the seed regulatory system.

Though this evidence was not conclusive about the transferability and diffusion effect of PBR, it does reveal that PBR induces positive response from foreigners seeking to protect their plant varieties, thus PBR plays a role in affecting investment and research.

2.4.4 Impacts on Distribution of Benefits and Industry Structure

PBRs, like other IPR instruments, imply a trade-off: stronger protection of IPRs would increase market power of IPR holders and probably induce them to reduce output or sales in order to support higher monopolistic prices. From an economic perspective, this issue is about the redistribution of welfare benefits accompanying the introduction of new production technology in the form of improved varieties. To examine the distribution of benefits, one way is to analyze the price of improved seed varieties and compare any margin over existing varieties; another way is to examine the distribution of benefits between farmers, consumers and the seed sector (Eaton, 2002). However, no existing literature has examined the distribution of benefits between farmers, consumers and the seed sector specifically for PBRs.

If there are monopoly powers in the hands of seed suppliers as a result of PBR, one could expect excessive margins on the prices of protected varieties. Lesser (1994) used econometric techniques (hedonic pricing model) to examine the marginal price associated with PVP certificates for soybean in New York State. Excluding other factors, he found evidence of 2.3% price increase associated with soybean varieties with PVP and concluded that U.S. PVP protected varieties were very similar associated with small monopoly rents. Another study was conducted in China, after it passed the PVP Act in 1997. Hu et al. (2006) used a system model to study the impact of PVP on rice seed prices in three big rice provinces from 1999-2002 and they found PVP does not show much impact on seed price. The PVP protected varieties increased seed price by only 0.84 Yuan/kg over non-PVP varieties. Lesser (1997) provided some explanations for the low monopoly rents: the reduced appropriability due to farmer-saved seed competition and the important role of public sector breeding programs.

Lesser (1998) indicated the impact of IPRs on the industry structure concentration in the agricultural biotechnology is contradictory. Some evidence showed that IPRs strengthened the incentive to invest which provides greater opportunities to larger firms and enhanced concentration (Phillips 1966; Mansfield 1962). However, other studies indicated that innovation contained deconcentration as well by finding entrant firms have a greater incentive to initiate radical innovation (Gort and Klepper, 1982; Winter 1984).

In the agricultural biotechnology industry, IPRs are changing the industry structure and the 1990s have witnessed acceleration in the process of consolidation in the agricultural biotechnology industry (Wright and Pardey 2006; Srinivasan 2003). The development of a new plant variety may require access not only to existing varieties protected by PBR but also to biotechnology processes or research tools that may be protected by patents held by several different companies. Thus, industry consolidation can permit the control of IPRs over relevant technologies that can provide secure access to technologies and reduce transaction costs.

The empirical evidence about the PBR effect on industry concentration is extremely limited. The only available study is from Srinivasan (2003), who studied the concentration in ownership of plant variety rights for six major crops in 30 UPOV member countries. Using the CR-10 ratio and the CR-4[1] ratio as the measure of concentration, he found several results: first, concentration in the ownership of PBR grants was high at the level of individual countries; second a very large proportion of grants was held by a limited number of large multinational seed companies; third, the overall concentration was less in crops where the public sector plays an important role in plant breeding such as wheat, soybean, the degree of concentration for these crops is much less than it is in maize and oilseed rape; fourth, concentration came resulted from the mergers and acquisitions; and finally concentration corresponded closely to concentration in the market share for seed.

[1] CR-4 ratio: the sum of the market shares of the top four firms. If the CR-4 ratio is less than 40%, the industry is considered to be competitive; a CR-4 ratio of 40-60% represents moderate to high levels of concentration. See more details on (Schmalensee and Willig, 1989).

His findings showed that the remarkable process of consolidation of the seed industry in the developed world had resulted in significantly concentrated ownership of PVP grants at the country level.

The relationship of IPRs and entry barriers is also an important area of study in the literature. There were concerns that concentration of IPRs by firms may create entry barriers and IPRs may play an additional role in limiting entry into the agricultural biotechnology sector (Lesser 1997; Lesser 1998). However, empirical studies examining the role of PBR on industry entry barriers have been quite sparse. The available studies examined the impact of patents protection on market entry in agricultural biotechnology industry. Barton (1998) found the use of broad patents such as the biological pesticide of Bt tended to force all competitors out of the market. Lesser (1998) indicated that patents and other factors (threat of litigation, material transfer agreements) can be used to deter market entry and indirectly accelerate concentration.

IPRs such as PBR are complex in the agricultural and plant breeding industry. Though theoretically PBR are considered to reduce competition and lead to more monopoly rents paid to breeders, empirical evidence found no consistent results by showing price of protected varieties increased slightly and the monopoly rents were modestly small. With regard to the impacts on industry structure, PBR seems to have significant structure impacts by encouraging industry concentration through mergers and acquisitions; however, the specific role of PBR in market entry is still inconclusive.

2.5 The 1990 Canadian PBR Act

Amongst developed countries, the Canadian PBR Act is relatively new having been enacted in 1990. One of the requirements of the Act requires the Canadian

Food Inspection Agency to review the impacts of the Act and the performance of the PBR system in general in meeting the stated goals of the Act. The CFIA reviewed the impact of the PBR system on crop yield and R&D investment for both agricultural (e.g., canola, wheat) and horticultural crops.

The CFIA review examined the activities related to PBR applications and rights granted with some interesting results. The key findings of the review are mentioned in chapter one in the introductory part of the thesis. That is: investments from the private sector increased; access to foreign varieties by growers improved; and the development of improved varieties increased. However, as we have discussed before, the finding of the review is inconclusive for several reasons. First, most of the information from the data is based on the opinions of industry representatives. Thus, this information could be subjective and not reliable. Second, the findings are mostly qualitative and are not rigorous and may not reflect the real impact.

With regard to the relationship of the PBR Act and public research investment, Carew (2000) studied the implications of evolving IPRs in Canada for the canola sector and public sector research. He found the majority of the certificates were granted to canola, potato and soybean with fewer certificates to wheat and barley, which was consistent with the findings of the CFIA review. Moreover, he concluded that canola attracts more private plant breeding investment because of the great profit potential for private industry (for example, the potential for genetic improvements such as hybrid varieties; the responsiveness of canola to genetic manipulation such as doubled haploids from microspores, tissue culture, protoplast fusion and gene transfer).

2.6 The Impact of Plant Breeders' Rights on Wheat

Unlike those hybrid crops such as canola, wheat is an open-pollinated crop and the varieties of open-pollinated varieties are homozygous which means the genotypes remain virtually unchanged across generations (Venner, 1997). Thus, if farmers save and replant seed from a previous harvest, the agronomic performance will typically be the same for the open-pollinated varieties and this poses a negative impact for breeders or owners as they can only receive partial royalties partially. Using the technology of hybridization, breeders can secure the economic property rights to a portion of the attributes in the improved characteristics of the variety (the agronomic performance is considerably lower in the second round of a hybridized variety). Nevertheless, Eaton (2006) pointed out that for many open-pollinated food crops such as wheat, rice and soybeans, either the technique of hybridization has not been successful or it entails costs that exceed the income stream that can be obtained from the additional attributes. Therefore, it is likely that the unique characteristics of wheat as an open-pollinated crop can cause some difficulty of capturing rents for plant breeders and thereby reduce the incentives for R&D.

One the other hand, Carew (2000) indicated that the stringent quality parameters for wheat imposed by the Canadian Wheat Board and the Canadian Grain Commission tend to restrict genetic modification within the Western Red Spring wheat class and since this wheat class dominates the Canadian market, it discourages private investment for wheat.

Likewise, besides examining the PVPA effect on wheat productivity and investment in the U.S., Venner (1997) also provided a comprehensive study of the effect of PVPA on the adoption of varieties with PVP certificates, wheat seed price and grain quality. He indicated the commercial failure of hybrid wheat and the less than expected appropriation from protected varieties both discouraged private investment. Yet he pointed out that the adoption of varieties with PVP certificates have increased for both private and public varieties, which is consistent with the hypothesis that PVPA increased the share of wheat acreage to private varieties. Furthermore, his result showed that PVPA did not appear to have significantly increased wheat seed and grain quality. In sum, he concluded that PVPA have not contributed to higher yields of wheat varieties and did not increase private sector investment in wheat breeding, but rather served as a marketing tool to boost the share of what acreage to private varieties.

Since previous studies found the different effects of the PBR Act on crop yield, it is possible that the effect of the PBR Act varies among different crops. As no empirical study has investigated the economic effect of the PBR Act on other crops except canola in Canada, there is need to replicate the U.S. study to examine the effect on wheat in Canada. Furthermore, wheat is different from canola with its open-pollinated characteristics which may discourage incentives to investment. Thus there is a need to examine empirically the relationship between PBR Act and wheat productivity to have a better understanding of the economic effect of the PBR Act in Canada.

2.7 Current Issues around PBR in Canada

Lesser (1997) indicated that there is still a lack of economic research studying the intellectual property protection for plant varieties and this applies to research in both industrialized and developing countries. Although the Canadian PBR Act was enacted in 1990, it has never been without controversy. Mostly the debates are about what aspects of the PBR regime should be further strengthened since the current Canadian PBR Act adheres to the 1978 UPOV.

Perhaps the most controversial issue is how to address the "farmers' privilege". The 1978 UPOV Convention assumed that farmers are permitted to save and reuse seed of protected varieties for private and non commercial use. However, the 1991 UPOV Convention limits "farmer's privilege" by stating that on-farm seed saving is not permitted without the consent of the breeders though the conditions may vary according to member states. Moreover, the 1991 Convention prohibits any transfer of seed of protected varieties between farmers (The World Bank, 2006). However, the "farmers' privilege" is not explicitly stated in the 1990 Act in Canada. Thus the current PBR Act would not exempt farmers from obtaining authorization from the holder of the rights before they sell seed produced from a protected variety as a seed for planting. This may probably weaken the intellectual property protection for breeders and may further reduce the incentives for investment. Plant Breeders' Rights amendments have been discussed by different stakeholders, the Canadian seed industry, the Western Canadian Wheat Growers Association, the Plant Breeders' Rights Office and representatives from horticulture and agriculture industries. These industry representatives are trying to bring the PBR Act into compliance with the 1991 UPOV Convention in terms of extending the protection period and rights to conditioning, exporting and importing propagation materials; and allowing one year sale prior to application coupled with allowing commercial sales while the application is pending (Canadian Food Inspection Agency, 2002).

Specifically, with regard to the restriction of "farmer's privilege", the recommendation is to explicitly state that a plant breeder's rights do not extend to " the conditioning and use of harvested material of the plant variety by a farmer on the farmer's holdings for subsequent reproduction by the farmer of the plant variety on the farmer's holdings" so that farmers are permitted to plant the harvested material on any land the farmers may subsequently own or rent (Western Canadian Wheat Growers Association, 2005). However, opposite voices from farmers argue that the proposed change taking away farmers' rights to save, reuse and exchange seeds will criminalize the age-old customary practices of farmers. By giving seed companies additional years of royalties, it is a costly blow to farmers but a profit windfall for those seed companies (The Star-Phoenix, 2004).

With regard to breeder's exemption, it is even more controversial. Critics state that this would allow transfer of a gene construct to a protected variety with no ownership rights and should be limited in light of technological advances (Lesser, 2005). To prevent its negation of variety rights, the 1991 Convention adds the limitation on "essentially derived varieties (EDV)" for breeder's exemption. Under the 1991 Convention, EDV cannot be exploited in certain circumstances without permission of the person or entity that holds the rights to the original variety. In Canada's proposed amendments of the PBR Act, it considers the EDV will strengthen the PBR Act without limiting the breeders' exemption and as a consequence provide compensation to the original inventor (Carew, 2000). However, Lesser and Mutschler (2004) examined the current dependent variety system and found it to be unworkable probably because of the function of PBR as protecting the entire plant but not specific traits. Moreover, it is feared that some large companies would monopolize certain gene pools (ISF, 2005).

Regarding those controversial issues surrounding the PBR Act, the debate needs to be better informed in terms of evaluating what the impacts have been thus far. That's the motivation and objective of this study.

2.8 Summary

In this section, three topics were reviewed. First, three interrelated economic roles of IPRs (patents) were examined: to provide incentives for innovators, to encourage technology transfer, and to improve welfare through the provision of improved products. In this part, an overview of the relationship between IPRs and growth and productivity was also studied with the consensus that IPRs had a positive role on long run growth and productivity. The second part discussed the economic impact of PBR from different perspectives: the impact on R&D investment was still inconclusive; the effect on output and crop productivity varied among different countries; the impact on international technology transfer was positive as to its impact on R&D investment, but it needs further examination; the impact on welfare and the distribution of benefits indicated low monopoly rents went to seed suppliers; and the impact on the industry structure showed significant concentration in the agricultural industry but inconclusive on the market entry. In the third part, the Canadian PBR Act and wheat PBR studies were highlighted along with the current controversies surrounding the PBR Act in Canada.

Chapter 3: Data and Methodology

3.1 Introduction

Has the Canadian Plant Breeders' Rights Act (PBR Act) led to improved varieties (higher-yielding) as claimed in the 2001 review of the Act by the Canadian Food Inspection Agency? As indicated in the Chapter 1, the evidence in support of the productivity effect of PBR is uncertain in light of the fact that the observable gains in wheat yields in western Canada appear to fluctuate or weaken, just when they might have been expected to have increased as a result of the PBR Act. In this chapter we describe our empirical methodology to test the relationship between the PBR Act and wheat productivity in Canada. Two models are developed: one tests the relationship at the aggregate level using data from Canada's western provinces while the other uses more detailed varietal level data for the province of Alberta. Before describing the models we first review previous research to discuss the factors influencing wheat yields and present a conceptual framework to examine the relationship between wheat yield, PBR and other explanatory variables. In the sections that follow, the data and the models used are described.

3.2 Previous Research

Much of the previous literature has used yield functions to examine the effects of production inputs and environmental factors on crop yields (Offutt et al, 1987; Dixon, 1994; Yang et al, 1992). Generally, linear yield functions have been preferred over nonlinear models to estimate the effect of climate and technology on crop yields. Some previous research combines an index of varietal improvement with econometric analyses to examine the determinants of experimental wheat yields (Feyerherm et al., 1988; Babcock and Foster 1991).

Of all the factors that have been considered to explain wheat yield, production inputs such as fertilizer are consistently the most significant variable explaining the variation in wheat yield (Bell et al. 1995; Traxler et al, 1995; Edwards and Furtan 1998). Environmental factors such as soil condition, herbicide and climatic conditions have also been shown to affect crop yields. Feyerherm and Paulsen (1981), Burt (1995), Teigen and Thomas (1995) and Venner (1997) employed weather variables in their experimental and commercial wheat yield models. In Canada, Campbell et al. (1988) and Campbell et al. (1997a) used precipitation and temperature variables in their experimental yield model for red spring wheat in western Canada. The results from their studies showed temperature and precipitation explained the variation in spring and Durum wheat yields. Other studies also found interaction terms between nitrogen and precipitation, temperature and precipitation were positive and significant variables impacting wheat yield (Burt 1995; Teigen and Thomas 1995).

While physical inputs and environmental factors are clearly important factors affecting yields, institutional and market forces can also affect productivity. Crop prices are expected to increase the value of the marginal product of inputs since they are expected to stimulate crop planting and thereby lead growers to apply greater quantities of variable inputs. Institutional factors, such as the PBR Act, are expected to contribute to higher crop productivity as the PBR Act is expected to induce private R&D in plant breeding and thus lead to more productive varieties with varietal improvements. The impact of the PBR Act on output and productivity has been discussed in the literature review. In this section, we focus on different methodologies employed to test the impact of PBR Act on crop productivity.

Venner (1997) for example examined the relationship of the PVPA on wheat yields by employing commercial and experimental yield functions. For the commercial wheat yield model, after controlling for other environmental and input factors, Venner used the share of acreage sown to wheat varieties with PVP Certificates to test their effects coupled with an intercept dummy variable to test for structural break effects after the passage of the PVPA. Similarly, Carew and Devadoss (2003) tested the effects of the PBR Act on canola yields in Canada by using the share of seeded area of varieties with PBRs and included a dummy variable to measure the structural change effect after the passage of PBR Act. But unlike Venner's single yield equation, Carew and Devadoss (2003) applied panel data models to test the relationship of the PBR Act on canola yields which also compared the estimates from the covariance model (fixed effects) and random effects model. Likewise, Naseem et al (2005) applied a panel data models to examine cotton yields in the United States and they included other explanatory variables such as the interaction term of the share of PVP varieties and a trend term to quantify whether this form of varietal protection affected yield.

The three studies investigated the impact of the PBR Act/PVPA on crop yields but with different results. This may be attributed partly to different estimation approaches adopted coupled with the use of varied data sets and levels of data aggregation. The results from Carew and Devadoss (2003) and Naseem et al. (2005) showed positive impacts, while Venner's (1997) results did not. One possible explanation is that panel data models used by Carew and Devadoss (2003) and Naseem et al. (2005) can better control for the unobservable individual effects for temporal and spatial crop yield data. In addition, as the three studies examined different crops (wheat, canola and cotton), it is possible that the PBR Act has different impacts on different crops.

3.3 Conceptual Framework

Based on our hypothesis that the adoption of wheat varieties qualifying for Plant Breeders' Rights has increased overall wheat yields and rate of yield increase, it is possible to test this hypothesis at different levels of aggregation: the impact on wheat yields for four provinces in western Canada and the impact on wheat yields for the province of Alberta where different wheat classes and soil zones are considered in the analyses.

Based on the evidence from previous studies, there is an advantage in using panel data models comprising time series and cross sectional data. However, the use of panel data models is limited by the nature of our data. While the western Canada and Alberta wheat yield data contain both time series and cross sections, they are not suitable for panel data analysis. For example, the wheat data for western Canada (Manitoba, Saskatchewan, Alberta and British Columbia) consisted of 135 observations for five wheat classes (Western Red Spring, Durum, Western Red Winter, Extra Strong and Soft White Spring) over a nine year period. This three dimensional data (class, province, year) set did not satisfy the data configuration required for a panel data analysis. When separated by wheat class, the numbers of observations for each class are 36 (Western Red Spring), 26 (Durum), 27 (Western Red Winter), 27 (Extra Strong) and 19 (Soft White Spring). For the Alberta data, the yield covers the individual variety level for five wheat classes in eight soil zones over a five year period (199-2003). Similarly, the Alberta data were limited for a panel data analysis by also having three dimensions (variety, soil zone and year). As a result of these data limitations, alternative estimation approaches were investigated.

Following Venner (1997), we adopt a yield response function for the wheat yield study in western Canada and Alberta. In equation (3.1), yield of wheat class c in province s in year t (Y_{cst}), depends on whether a variety is protected by PBR (P_{cst}), the quantities of production inputs (X_{st}), and climatic variables (precipitation, temperature) (W_{st}). In addition to these quantitative factors, qualitative factor (M) such as provincial dummy variables is included.

$$Y_{cst} = f(P_{cst}, X_{st}, W_{st}, M) \tag{3.1}$$

For Alberta wheat yield data, the response function will be a modified version of equation (3.1). The yield of wheat variety i in each class in soil zone r in year t depends on the number or share of varieties qualifying for PBR (P_{irt}), the quantities of production inputs (X_{rt}), and climatic factors such as the precipitation and temperature (W_{rt}). Likewise, some qualitative factors (M) such as variety and soil zone dummy variables are included in the function.

$$Y_{irt} = f(P_{irt}, X_{irt}, W_{irt}, M) \tag{3.2}$$

The main difference between the two yield response functions is that equation (3.1) examines the relationship between wheat yields at the provincial level and associated factors influencing them while equation (3.2) studies the relationship between wheat yields at the individual variety level in each class and factors influencing them. The strength of the equation (3.1) is that it investigates the wheat yields in western Canada where 97% of the wheat is grown while the strength of equation (3.2) is that it examines the variety wheat yield for different wheat classes. The disadvantage is that both models are single equations, without considering temporal and spatial aspects of the data. Consequently, the unobserved individual effects are not well accounted for in the wheat yield functions. In the next section, we specify the empirical models for both equations and describe the data employed.

3.4 Empirical Model for Western Canada and Data Description

3.4.1 Wheat Yield Model for Western Canada

A linear empirical wheat yield model is developed for wheat yield in western Canada to identify the relationship between wheat yields and explanatory variables such as share of acreage devoted to varieties qualifying for PBR rights, production inputs, regional influences and environmental factors.

$$Yield_{cst} = \beta_0 + \beta_1 PBR_{cst} + \beta_2 NPBR_{cst} + \beta_3 price_{cs(t-1)} + \beta_4 precipitation_{st}$$
$$+\beta_5 temperature_{st} + \beta_6 Acre_{cst} + \sum \beta_7 M + \varepsilon_{cst}$$

Where

$Yield_{cst}$ = the average yield of wheat for a given wheat class c in province s and in year t, measured by bushel per acre

$Area_{cst}$ = the total area planted to the class of wheat c in province s in year t, measured by 1,000 acres

PBR_{cst} = the share of wheat acreage sown to varieties with PBR rights for a given wheat class c in province s in year t

$NPBR_{cst}$ = the share of the number of PBR varieties for a give wheat class c in province s in year t

$price_{cs(t-1)}$ = the producer price of wheat for wheat class c in year $t-1$

$precipitation_{st}$ = sum of precipitation from May 1st to July 31st for selected stations in wheat growing areas in province s in year t

$temperature_{st}$ = sum of daily mean temperature minus 5 degrees from May 1st to Aug 31st in selected weather stations for wheat growing areas in province s in year t

M_{ct} = qualitative dummy variables such as provincial dummy variables and wheat class dummy variables

3.4.2 Description of Wheat Data in Western Canada

Summary statistics for the data used in the wheat yield functions in western Canada are shown in Table 1.

Table 1: Summary Statistics of Wheat Data in Western Canada (1998-2006)

Variable	Obs	Mean	Std. Dev.	Min	Max
Yield	135	41.48	14.82532	20	107
Area	135	1507.689	2574.403	5	10700
PBR	135	21.31333	26.05152	0	86.4
NPBR	135	0.196126	0.202443	0	0.833
Price	135	5.292219	0.803542	3.948	7.300457
Precipitation	135	187.6754	45.74514	107.9889	309.68
Temperature	135	1243.559	145.6988	955.48	1472.02

Source: Statistics Canada (1998-2006), Canadian Wheat Board (1998-2006)
Canadian Food Inspection Agency PBR Office (2006a), Environment Canada (1998-2006)

There are eight classes of wheat grown in Canada and their respective end uses are in parentheses: Western Red Spring (pan bread, alone or blends for hearth bread, steamed bread, noodles, flat bread, common wheat pasta), Western Red Winter (French breads, flat breads, steamed breads, noodles), Western Extra Strong (blending and used in specialty products when high gluten strength is needed), Prairie Spring Red (hearth breads, flat breads, steamed breads, noodles), Prairie Spring White (flat breads, noodles, chapattis), Western Amber Durum (Semolina for pasta and couscous), Western Soft White Spring (cookies, cakes, pastry, flat breads, noodles, steamed breads, chapattis) and Western Hard white Spring (bread and noodle production) (Canadian Grain Commission, 2007). However, due to data availability, only five classes of the wheat yield data were analyzed in the four western provinces: Western Red Spring (WRS), Western Amber Durum (Durum), Western Red Winter (WRW), Western Extra Strong (WES), and Western Soft White Spring (WSWS).

Table 2 shows the number of wheat varieties protected by PBRs for each wheat class. Wheat varieties belonging to WRS wheat class had the largest number of varieties that were protected by Plant Breeders' Rights. Wheat varieties belonging to other wheat classes had a relatively smaller number of varieties that were granted Plant Breeders' Rights. The smaller share of PBR varieties for WRW and WES wheat classes may reflect the smaller area seeded to these wheat varieties in western Canada.

Table 2: Number of Varieties and PBR Varieties planted in Western Canada (1998-2006)

Year	WRS	PBR WRS	Durum	PBR Durum	WES	PBR WES	WRW	PBR WRW
1998	23	5	7	2	4	0	4	0
1999	27	7	10	4	4	0	4	0
2000	28	7	9	3	6	1	7	0
2001	28	7	9	3	6	1	6	0
2002	29	6	9	3	7	1	8	0
2003	31	10	10	4	8	1	12	1
2004	32	11	10	4	8	1	12	1
2005	29	16	10	4	10	1	13	2
2006	30	20	7	6	10	1	13	2

Source: Canadian Wheat Board (1998-2006) and
Canadian Food Inspection Agency PBR Office (2006a)

Note: WRS: variety numbers of Western Red Spring wheat;
PBR WRS: varieties numbers of Western Red Spring Wheat with Plant Breeders' Rights;
WES: variety numbers of Western Extra Strong wheat;
PBR WES: variety numbers of Western Extra Strong wheat with Plant Breeders' Rights;
WRW: variety numbers of Western Red Winter wheat;
PBR WRW: variety numbers of Western Red Winter wheat with Plant Breeders' Rights.
There were no PBR varieties in the WSWS wheat class.

With regard to the yield performance in each province, Figures 7 to 11 shows the annual wheat yield for the five wheat classes in western Canada. For each class, wheat yields varied among provinces. Yields fluctuated during 1998-2006 except for WSWS wheat. Since no varieties had PBRs in that class, the increase in yield can not be attributed to the PBR Act.

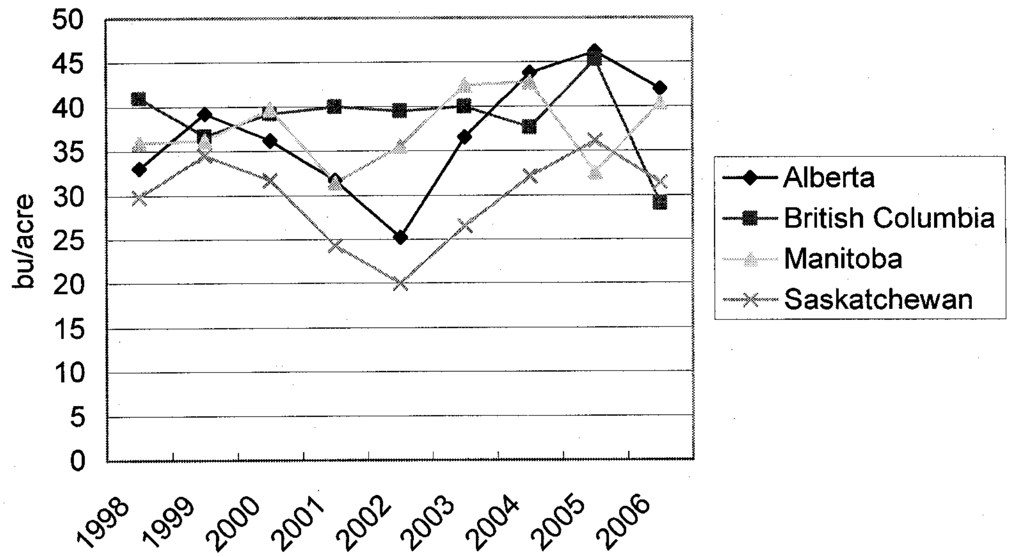

Figure 7: Annual Wheat Yield of Western Red Spring Wheat (1998-2006)
Source: Statistics Canada (1998-2006)

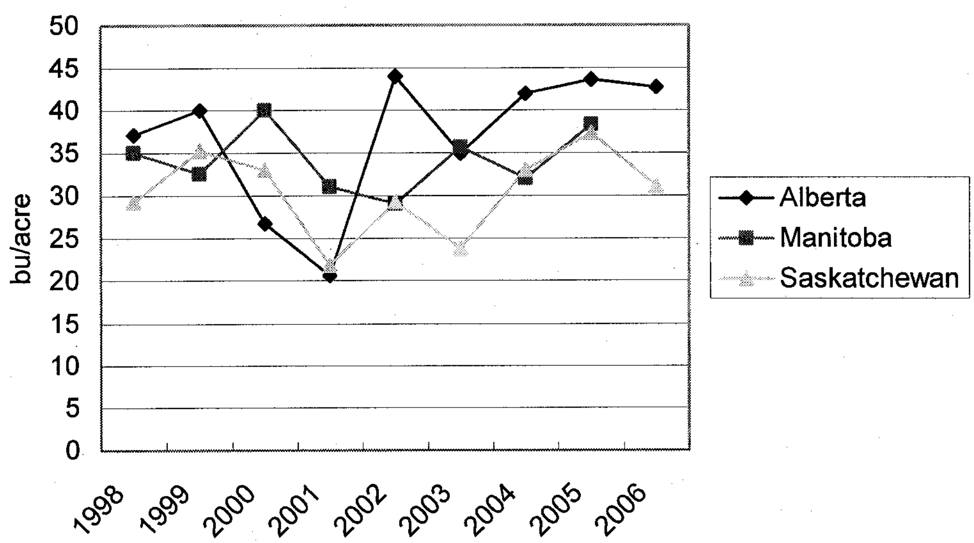

Figure 8: Annual Wheat Yield of Western Amber Durum Wheat (1998-2006)
Source: Statistics Canada (1998-2006)

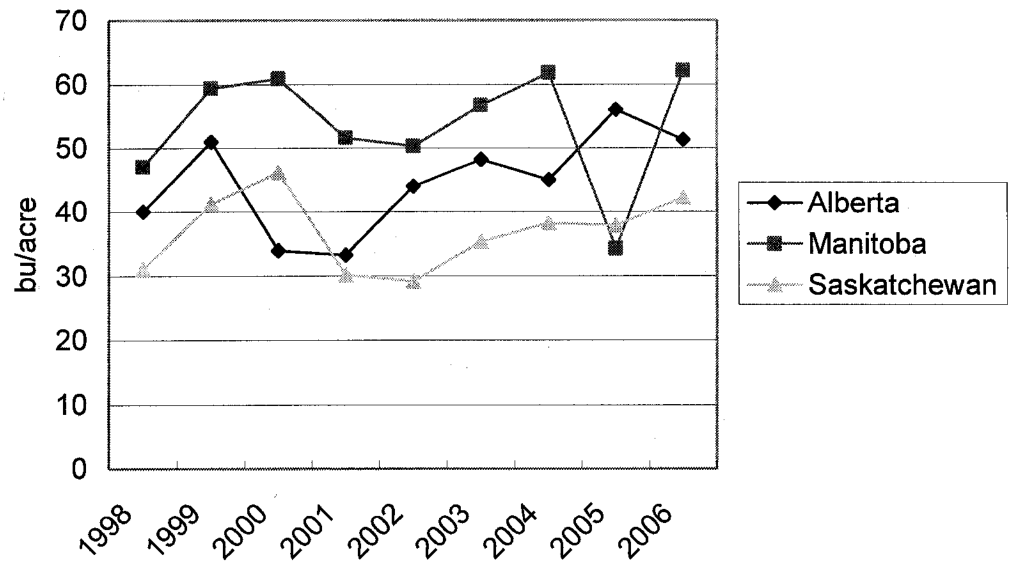

Figure 9: Annual Wheat Yield of Western Red Winter Wheat (1998-2006)
Source: Statistics Canada (1998-2006)

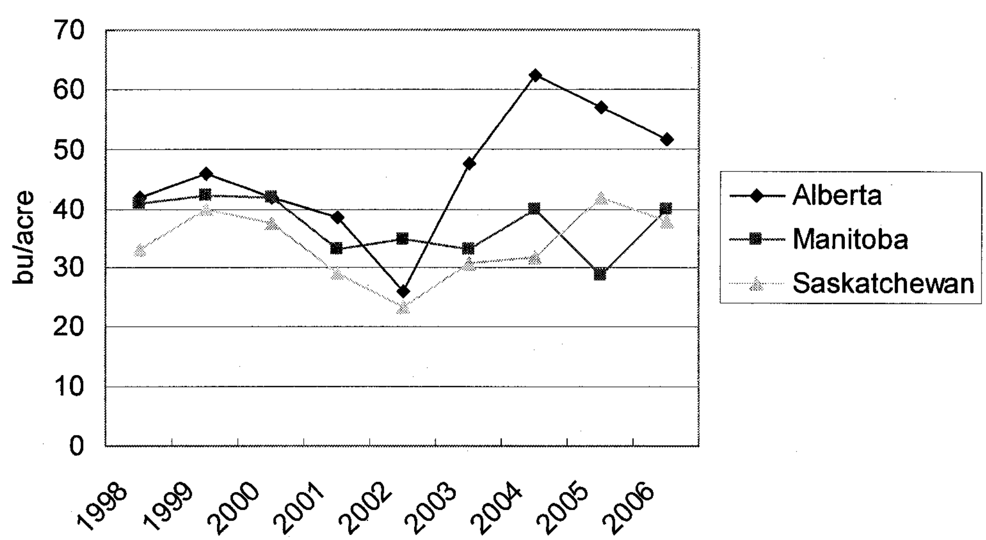

Figure 10: Annual Wheat Yield of Western Extra Strong Wheat (1998-2006)
Source: Statistics Canada (1998-2006)

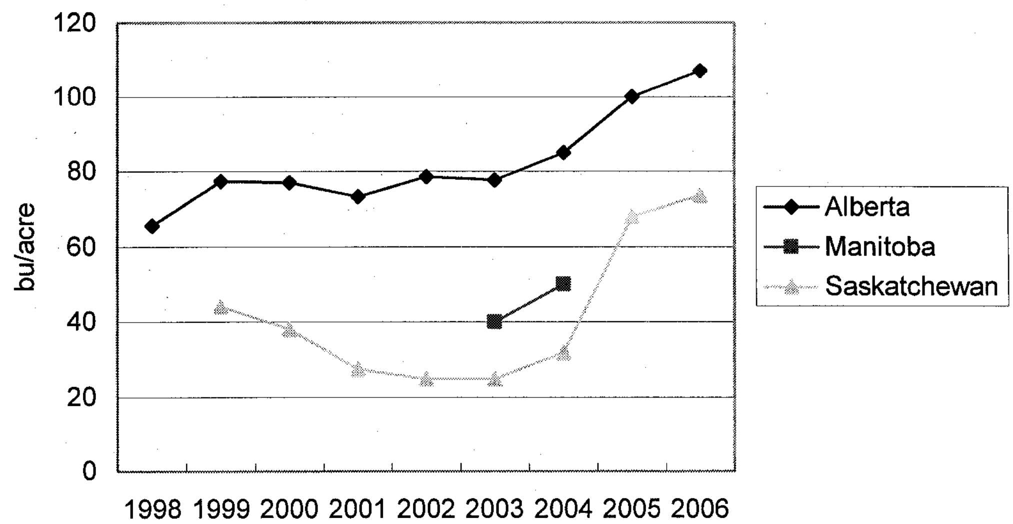

Figure 11: Annual Wheat Yield of Western Soft White Spring Wheat (1998-2006)
Source: Statistics Canada (1998-2006)

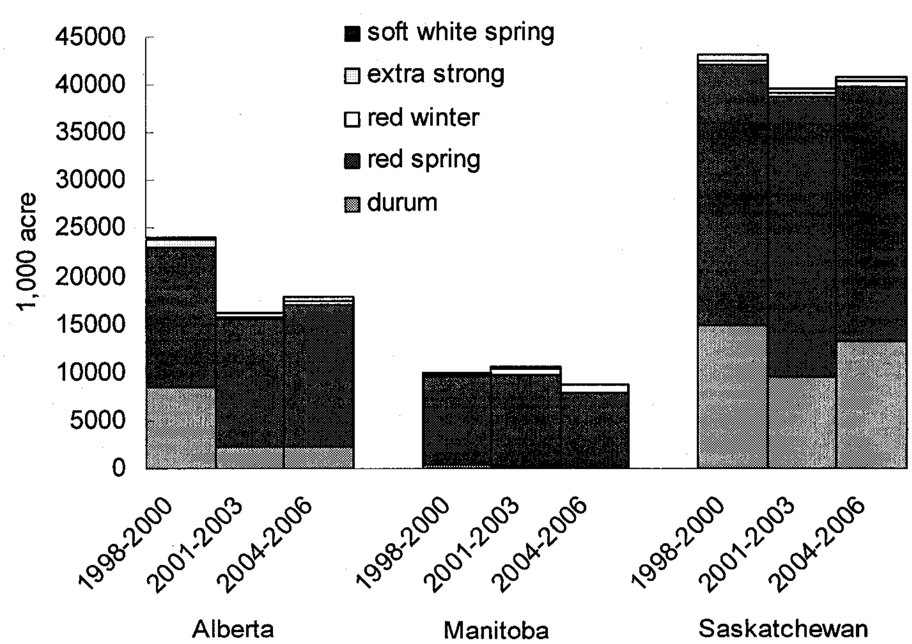

Figure 12: Seeded Acreage by Wheat Class in Western Canada (1998-2006)
Source: Statistics Canada (1998-2006)

Figure 12 illustrates the seeded acreage for the five wheat classes in Alberta, Manitoba and Saskatchewan. Of the five classes, WRS wheat is the largest category of wheat grown, followed by Durum, while the acreages of WES, WRW and WSWS are relatively small in each province.

Besides the PBR, yield and seeded area data, other production input and climate data were collected during 1998-2006. The quantity of production inputs is usually measured by the average quantity of fertilizer applied, yet it is not available at the provincial level for wheat. Thus a proxy to represent all other production inputs is the average producer price of wheat in the previous harvest year ($price_{t-1}$) as higher previous wheat prices lead profit-maximizing wheat growers to apply greater quantities of variable inputs (Venner, 1997). Figure 13 shows the producer wheat prices for the five wheat classes in western Canada. Prices were not stable for these years and Durum wheat reported the highest producer prices.

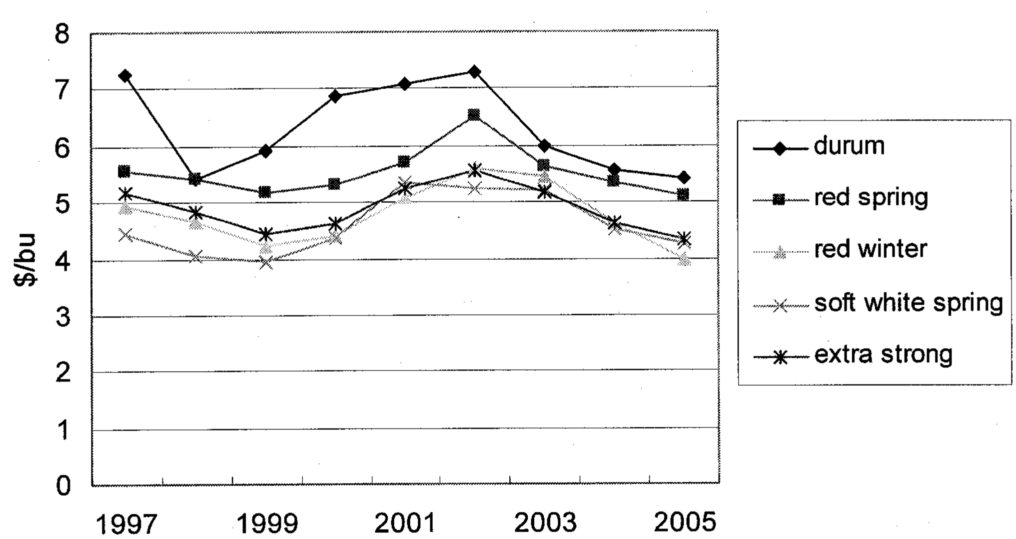

Figure 13: Producer Wheat Prices in Western Canada (1997-2005)
Source: Canada Wheat Board (1997-2005)

The model also includes weather variables to explain the variation in wheat yields as previous studies indicated precipitation and temperature did affect wheat yields in western Canada (Campbell et al., 1988 and Campbell et al. 1997a). The sum of precipitation form May 1st to July 31st will be the proxy of the precipitation factors as Campbell et al. (1988) found growing season precipitation was more effective in explaining spring wheat yields. The proxy of the temperature factor is the sum of mean daily air temperature minus 5 degree Celsius from the period May 1st to August 31st (Campbell et al., 1997a).

Environment Canada compiled detailed precipitation and temperature data from several stations by province. The daily temperature and monthly precipitation employed in this study were average observations from selected weather stations in wheat growing areas for each province. Figure 14 shows the major wheat growing areas in western Canada. British Columbia has a smaller wheat growing area, while for Alberta, Manitoba and Saskatchewan; most of the wheat growing areas are in the southern part of these provinces. Climatic data (precipitation, temperature) was collected from weather stations in the wheat growing areas of western Canada. Figures 15 and 16 show the trend of precipitation and temperature in each province.

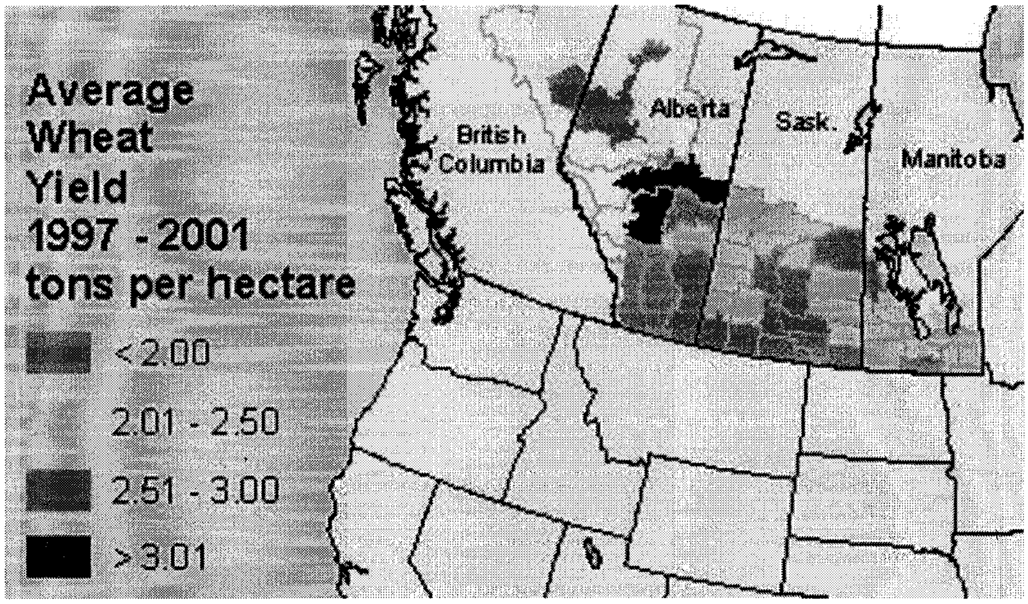

Figure 14: Map of Wheat Area Distribution in Canada
Source: United States Department of Agriculture (2004)

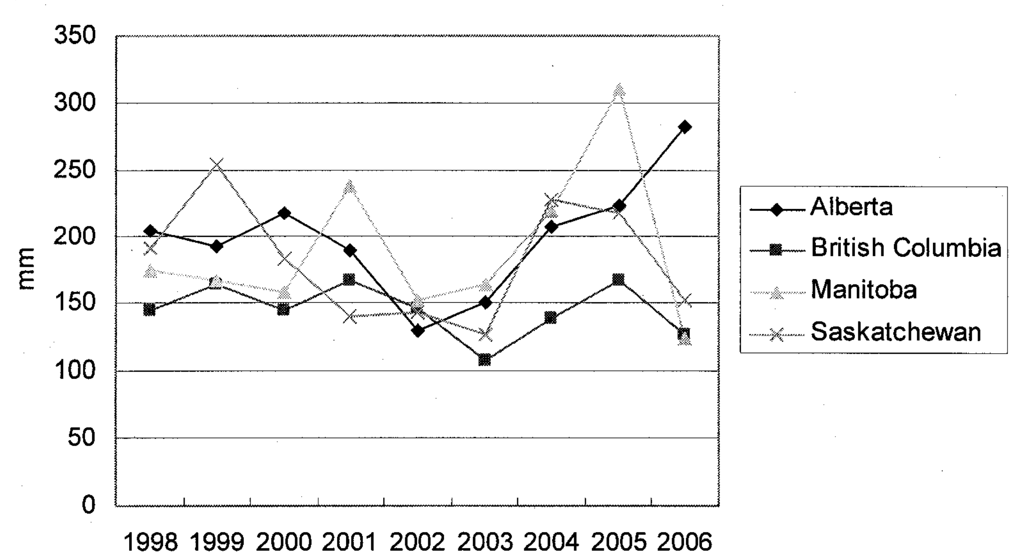

Figure 15: Sum of Precipitation from May to July (1998-2006)
Source: Environment Canada (1998-2006)

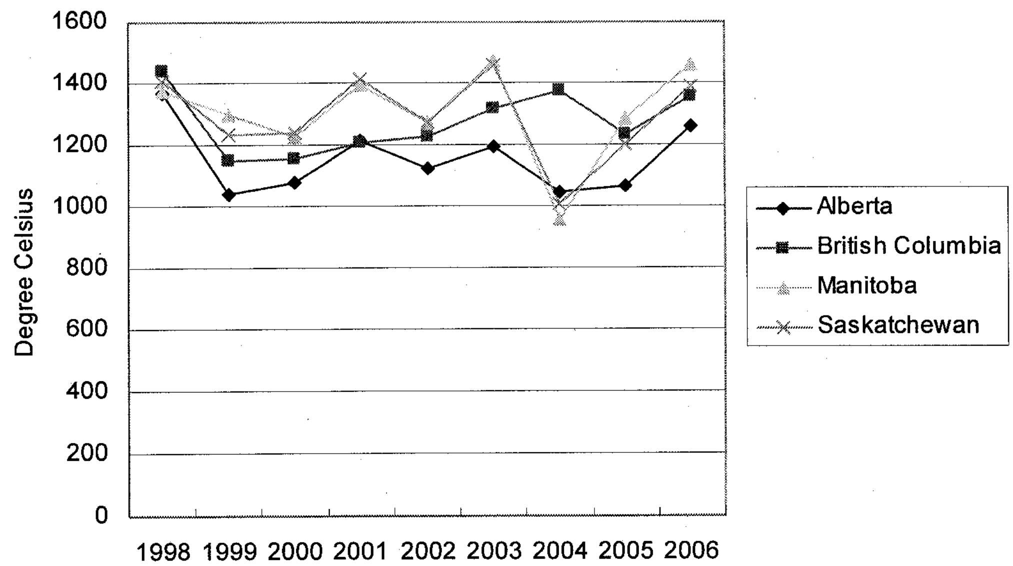

Figure 16: Sum of Daily Temperature from May to August (1998-2006)
Source: Environment Canada (1998-2006)

3.4.3 Estimation methods

To capture the effects of the PBR Act, two measures are employed. The first method involves the variable PBR_{cst} by testing the effect of the share of planted acreages devoted to PBR varieties. The second measure tests the effect of the share of the number of PBR varieties to all wheat varieties using variable $NPBR_{cst}$. A finding of a positive and significant coefficient on PBR_{cst} or $NPBR_{cst}$ will be indicative that the adoption of PBR varieties has increased wheat yields.

A number of preliminary regressions are tried for the model specification. Functional forms (log-linear, linear-quadratic) of the wheat yield function are examined to evaluate models that satisfy the goodness of fit standard. Models with log linear terms prove to be unsatisfactory since many observations of the variables PBR_{cst}, $NPBR_{cst}$ are 0 and were thus dropped, while several variables are statistically insignificant. Thus, the linear-quadratic model is employed for estimation.

Qualitative Provincial variables are likely to capture soil quality factors that are likely to affect yield. Since the provincial variable M is dichotomous, one of them must be dropped to avoid collinearity problem. In this case, one of the four provincial dummies should be dropped. The STATA software package is employed to analyze the pooled data with provincial dummies and by default it automatically drops one of them.

As the two PBR variables, PBR_{cst} and $NPBR_{cst}$ are likely to be collinear, we test for evidence of multicollinearity. And the correlation coefficient between the two variables is 0.86, which indicates the presence of multicollinearity between these two variables. Thus, the two variables will be included in separate models to avoid multicollinearity.

Since the time series and cross section data are analyzed by pooled regression, the error term may not have a constant variance and therefore heteroskedasticity may be a problem. We tested for it in STATA and it did exist, so the robust corrections were made for these regressions.

Results of empirical analysis will be presented later in the next chapter.

3.4.4 Plant Breeders' Rights on Public Wheat Varieties

As mentioned in chapter1, there were 102 wheat applications during 1992 to 2006, but only 52 were granted Plant Breeders' Rights. Of wheat PBR applications, Canadian public applications[1] comprise about 58%. Figures 17 and 18 illustrate the relationship between applications and rights granted for both public and private sectors. One objective of the PBR Act is to provide incentives for the private sector to undertake more R&D and develop improved varieties complementing the public research effort. It is apparent from Figures 17 and 18 that the PBR Act did not seem to have changed much the activities of the private sector since public varieties continued to dominate both application and rights granted.

Table 3 shows the applicant information for the number of wheat varieties granted rights. Agriculture & Agri-Food Canada received the largest number of rights followed by two private companies (Pflanzenzucht Oberlimpurg and Syngenta Seeds Canada Inc.). It is evident that most PBRs granted for wheat cultivars were from public institutions.

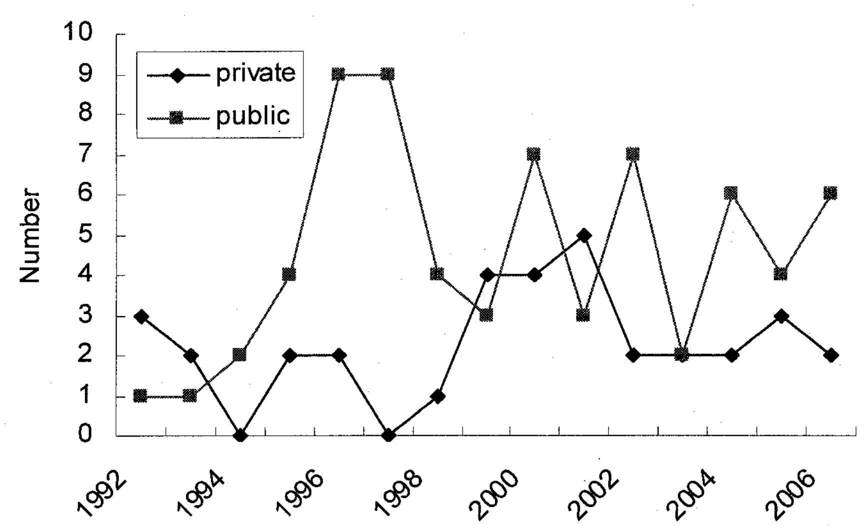

Figure 17: Number of Wheat PBR Applications (1992-2006)
Source: Canada Food Inspection Agency PBR office (2006a)

[1] An application is defined as a public application if the applicants are from government research institutes, universities or other research foundations, otherwise they are private applications. Likewise, the rights granted are defined by the nature of the applicants as well.

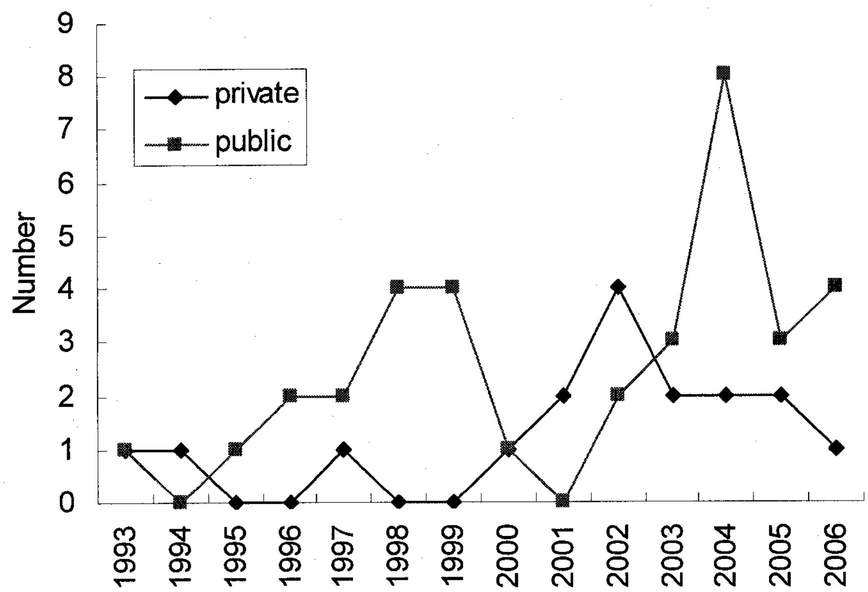

Figure 18: Number of Wheat PBR Rights Granted (1993-2006)
Source: Canada Food Inspection Agency PBR office (2006a)

Table 3: Information of Applicants with PBRs Granted (1993-2006)

Applicants	Number of PBRs	Type of institution	Country
Agriculture & Agri-Food Canada	26	Public	Canada
Pflanzenzucht Oberlimpurg	8	Private	Germany
Syngenta Seeds Canada Inc.	6	Private	Canada
NDSU Research Foundation	2	Public	U.S.
University of Manitoba	2	Public	Canada
Saskatchewan Wheat Pool	1	Public	Canada
The Ohio State University	1	Public	U.S.
University of Guelph	1	Public	Canada
University of Kentucky	1	Public	U.S.
University of Saskatchewan	1	Public	Canada
Virginia Tech Intellectual Properties, Inc.	1	Private	U.S.
W.G. Thompson & Sons Limited	1	Private	Canada

Source: Canadian Food Inspection Agency PBR Office (2006a)

Since the performance of wheat yields depend on the development of higher-yielding varieties and on the adoption by farmers, the practice of obtaining PBRs on public varieties can increase royalties and thereby lead to reinvestment into varietal development. Thus obtaining PBRs on public varieties may help to increase wheat productivity. However, it is not possible to test this hypothesis in our study as over 90% of wheat varieties planted in western Canada are public varieties.

3.5 Empirical Models for Alberta and Data Description

3.5.1 Farm Reported Wheat Variety Yield Models

Industry reported wheat variety yield data is used for the Alberta yield model, as it has five years of wheat variety data for five wheat classes in its eight soil zones. Unlike the models for western Canada, models for Alberta are estimated for different wheat classes.

$$Yield_{\text{irt}} = \beta_0 + \beta_1 PBR_{rt} + \beta_2 nitrogen_{rt} + \beta_3 phosphorus_{rt} + \beta_4 potassium_{rt} + \beta_5 sulphur_{rt} + \beta_6 precipitation_{rt} + \beta_7 temperature_{rt} + \beta_8 Z_8 + \sum \beta M + \varepsilon_{irt}$$

and

$$Yield_{\text{irt}} = \beta_0 + \beta_1 PBR_i + \beta_2 nitrogen_{rt} + +\beta_3 phosphorus_{rt} + \beta_4 potassium_{rt} + \beta_5 sulphur_{rt} + \beta_6 precipitation_{rt} + \beta_7 temperature_{rt} + \beta_8 Z_8 + \sum \beta M + \varepsilon_{irt}$$

Where

$Yield_{irt}$ = the average industry reported wheat yield of variety i in soil zone r in year t (bushel per acre)

PBR_{rt} = the share of acres devoted to variety i if it is protected in soil zone r in year t

PBR_i = dummy variable, if variety i obtained the PBR rights

$nitrogen_{rt}$ = sum of nitrogen applied for wheat in soil zone r in year t (Lbs per acre)

$phosphorus_{rt}$ = sum of phosphate applied for wheat in soil zone r in year t (Lbs per acre)

$potassium_{rt}$ = sum of potassium applied for wheat in soil zone r in year t (Lbs per acre)

$sulphur_{rt}$ = sum of sulphur applied for wheat in soil zone r in year t (Lbs per acre)

$precipitation_{st}$ = sum of precipitation from May 1st to July 31st in selected stations in wheat growing areas in soil zone r in year t

$temperature_{st}$ = sum of daily mean temperature minus 5 degrees from May 1st to Aug 31st in selected stations in wheat growing areas in soil zone r in year t

Z_8 = interaction terms

M = qualitative variables such as soil zone, variety

3.5.2 Data Description of Wheat Data in Alberta

Unlike the western Canada data, the data used for Alberta analysis are different in many aspects. First, yield data are at the variety level for different soil zones; second, different fertilizer elements are used to measure the impact of production inputs on yield. Summary statistics for the major variables used are shown in Table 4.

Table 4: Summary Statistics of Wheat Data in Alberta (1999-2003)

Variable	Obs	Mean	Std. Dev.	Min	Max
Yield	1039	33.69394	16.17381	1	80
PBR share	1039	0.034195	0.106567	0	1
Precipitation	1039	170.6905	85.72633	54	438.2
Temperature	1039	1200.466	193.1066	854.1	1667.7
Nitrogen	502	49.20892	19.42531	4	82.2
Phosphorus	502	22.69125	5.086418	13.38	38.23
Potassium	499	5.621222	5.990687	0	20.5
Sulphur	499	3.037355	3.029151	0	18

Source: Source: Alberta Agriculture and Food (2007a),
Canadian Food Inspection Agency PBR Office (2006a), Environment Canada (1999-2003)

From the industry reported variety yield data, there are five classes of wheat grown in Alberta: Hard Red Spring, Hard Red Winter, Durum, Extra Strong and Canadian Prairie Spring. Wheat yields and insured acres were collected from wheat varieties in eight soil zones in Alberta: black soil zone, thin black soil zone, black-dark gray soil zone east, black-dark gray soil zone west, brown soil zone, dark brown soil zone, gray soil zone and peace river soil zone. Figure 19 illustrates the location of the soil zones in Alberta.

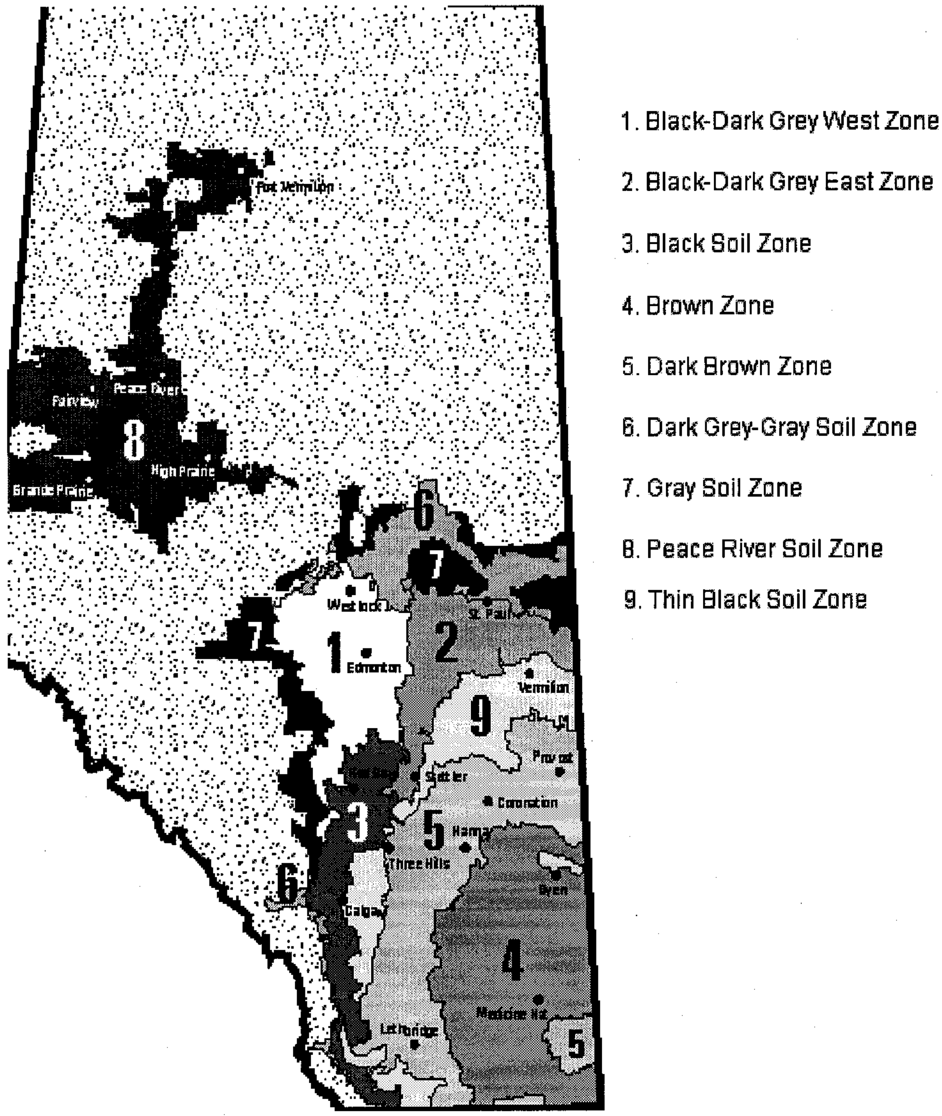

Figure 19: Location of Soil Zones in Alberta
Source: Alberta Agriculture and Food (2007a)

Table 5: Number of Wheat Varieties and PBR Varieties Planted in Alberta (1999-2003)

Class	No. of varieties	No. of PBR varieties
Hard Red Spring	39	13
Durum	14	3
Prairie Spring	11	4
Hard Red Winter	8	0
Extra Strong	5	0
Total	77	20

Source: Source: Alberta Agriculture and Food (2007a)
Canadian Food Inspection Agency PBR Office (2006a)

Regarding the PBR data, Table 5 shows the number of wheat varieties and PBR varieties planted for each wheat class in Alberta. Of the five wheat classes, Hard Red Spring wheat had the highest number of varieties protected by PBR rights (13) followed by Prairie Spring (4) and Durum (3). Wheat varieties of Hard Red Winter and Extra Strong had no PBRs granted to them in Alberta. Table 6 illustrates the summary statistics for the industry yield data by wheat class. It is evident that the mean yield for each wheat class differs but from the descriptive analysis, it is not possible to ascertain whether the yields for wheat varieties of classes protected by PBRs (Hard Red Spring, Durum, Prairie Spring) were higher than those varieties from the classes that are not protected by PBRs (Extra Strong, Hard Red Winter). Moreover, as the variety yield data were from different wheat classes, the data is analyzed by class to test our hypothesis[1].

[1] We analyze the Alberta data only for Red Spring, Durum and Prairie Spring wheat. For Hard Red Winter and Extra Strong wheat, there were no varieties protected and the observations are small, and consequently omitted from the analysis.

Table 6: Mean Yield of Wheat by Class in Alberta (1999-2003)

Class	Observation	Mean	Std. Dev.	Min	Max
Hard Red Spring	648	31.8519	14.092	1	67
Durum	115	25.7913	11.4221	3	51
Prairie Spring	185	44.627	20.2696	2	80
Hard Red Winter	30	30.4	13.9175	7	63
Extra Strong	61	36.623	15.6089	4	67
Total	1039	33.6939	16.1738	1	80

Source: Alberta Agriculture and Food (2007a)

Other data employed in the analysis included quantities of production inputs and climate data. The quantities of production inputs comprised the sum of various fertilizers elements applied for wheat in each soil zone over the 1999-2003 period. Wheat is very sensitive to insufficient nitrogen (N) and is very responsive to nitrogen fertilization. Based on previous research, wheat yields tend to increase with increasing rates of nitrogen fertilizer (Bell et al., 1995; Traxler et al, 1995; Edwards and Furtan 1998, Alberta Agriculture and Food, 2007d). Phosphorus (P) is a nutrient required in relatively large amounts by plants. A study conducted in Alberta from 1991 to 1993 to evaluate the responsiveness of wheat and other crops to phosphate fertilizer indicated the importance of phosphate fertilizer in crop production (Alberta Agriculture and Food, 2007b). Adequate potassium (K) results in superior quality of the whole plant due to improved efficiency of photosynthesis, increased resistance to some diseases, and greater water use efficiency (Alberta Agriculture and Food, 2007c). Without adequate sulphur (S), wheat can not reach its full potential in terms of yield or protein content, nevertheless wheat plants require less sulphur than other crops. Many soils in Alberta contain adequate sulphur for plant growth; however, a number of specific soil types are deficient in sulphur. The brown and dark brown soils in southern Alberta are generally not sulphur deficient. Sulphur deficiency can occur on thin black and black soils. Sulphur deficiency is very common in Gray soils in both central Alberta and in the Peace River region (Alberta Agriculture and Food, 2007e). Figure 20 shows the application rate of each fertilizer element in some soil zones. The rate of N application for wheat is highest among the four fertilizers followed by P, K and S. Brown soil zone has the lowest application rates of all fertilizer elements.

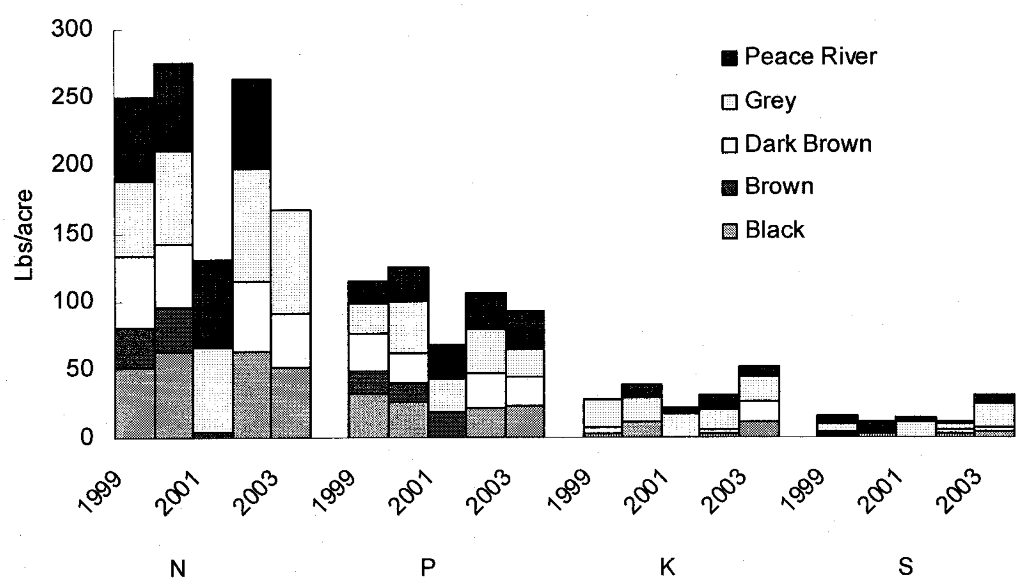

Figure 20: Application Rate of Fertilizers in Some Soil Zones (1999-2003)
Source: Alberta Agriculture and Food (Personal contact in 2007)

Since weather conditions influence the yield of wheat, precipitation and temperature are included as explanatory variables. The same measures of weather variables are used for Alberta. The only difference is that the precipitation and temperature are measured at the soil zone level. The average observations from selected weather stations in different soil zones are calculated based on the data supplied by Environment Canada. Figures 21 and 22 describe the precipitation and temperature trends for each soil zones in Alberta. The precipitation conditions varied among the soil zones, but in 2002 most soil zones experienced a shortage of precipitation and perhaps this may have contributed to the overall low yields in 2002. The temperature trends behaved similarly among the soil zones with highest temperatures reported in 2001.

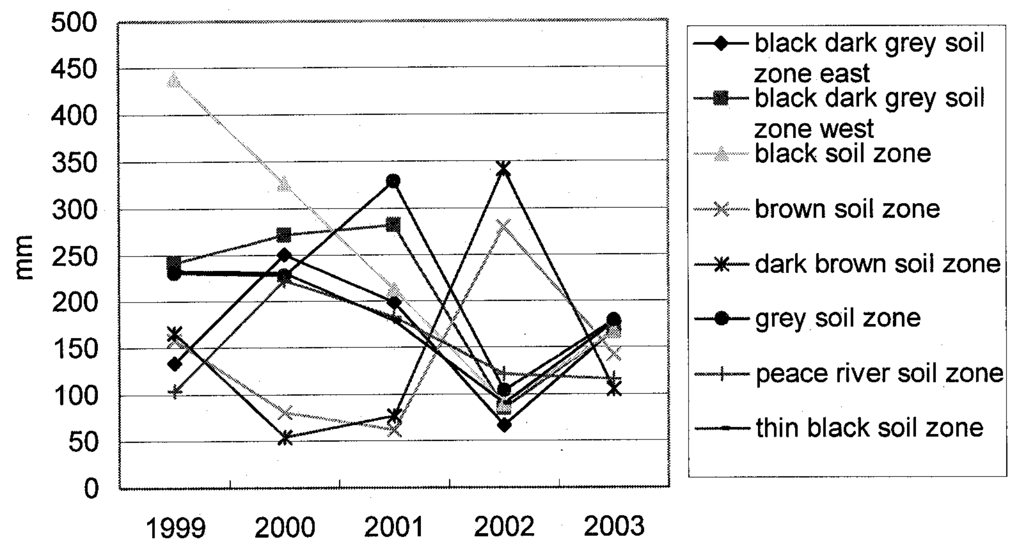

Figure 21: Sum of Precipitation from May to July in Alberta (1999-2003)
Source: Environment Canada (1999-2003)

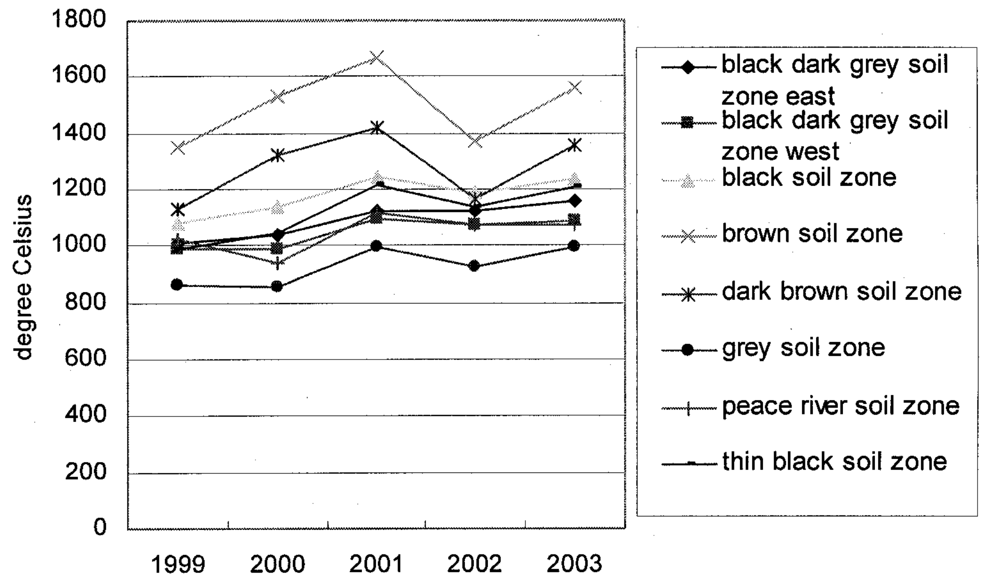

Figure 22: Sum of Daily Temperature from May to August in Alberta (1999-2003)
Source: Environment Canada (1999-2003)

Another difference of the Alberta industry reported wheat yield model in Alberta is that more qualitative variables (M) such as soil zone, individual variety characteristics are included in the model. Soil zone variable can be used as a proxy for the soil quality and other unobserved quality factors. Likewise, individual variety dummy variables will help to test whether some varieties have a greater effect on yield than others.

3.5.3 Estimation Methods

To test the effects of the PBR Act, two variable measures are adopted. The first involves the variable PBR_i based on whether PBR varieties are higher-yielding. If this is the case, it may indicate that additional revenues may be generated by PBR rights leading to greater research and investment and to further development of higher-yielding varieties. The second PBR measure uses the variable PBR_{rt} to examine whether increased PBR varietal acreage share will increase wheat yield.

Functional forms such as the log-linear or linear-quadratic were tested for the Alberta data but the evidence shows that the linear quadratic term performed better in having a better fit coupled with a greater number of variables that were significant. Different qualitative variables were included in the estimated regressions to avoid too much loss of degrees of freedom. Several diagnostic tests were undertaken including heteroskedasticity, omitted variable and multicollinearity. Heteroscedasticity and omitted variables is not a serious problem, but multicollinearity tends to be problem since there are many variables that were correlated with each other. The final model specifications used were those having the preferred signs for the coefficient estimates. The magnitude of the PBR coefficients did not vary very much for the different models tested.

The empirical results will be presented in the next chapter.

Chapter 4: Estimation Results of Wheat Yield Models

4.1 Introduction

The Plant Breeders' Rights Act (PBR Act) was expected to have led to improved wheat varieties (higher-yielding) for wheat varieties and impact wheat classes differently. In this chapter, the results of these hypotheses are tested and presented at different levels of aggregation: the provincial wheat yields in western Canada and the variety wheat yields in Alberta. The yield models and data were described in the previous chapter. This chapter presents the econometric results for key regressions and variables.

4.2 Results for Provincial Wheat Yields in Western Canada

4.2.1 Annual Gain in Wheat Yields

The estimated impact of PBR on provincial wheat yields in western Canada is based on the data from 1998 to 2006. According to the data, there are five classes of wheat: Hard Red Spring, Hard Red Winter, Extra Strong, Durum and Soft White Spring. In order to increase the number of observations in the sample, pooled regressions across different wheat classes are estimated. Figure 23 shows the annual wheat yield for the five wheat classes in western Canada. The yields of Soft White Spring wheat increased at a more rapid rate even though there were no PBR varieties reported for this wheat class. From Figure 23, there were yield gaps among these wheat classes and the yield gain in Soft White Spring wheat is evident while other classes having no clear yield gain pattern but fluctuations. Therefore, wheat class dummy variables are included in the regression models to capture the yield difference among wheat classes.

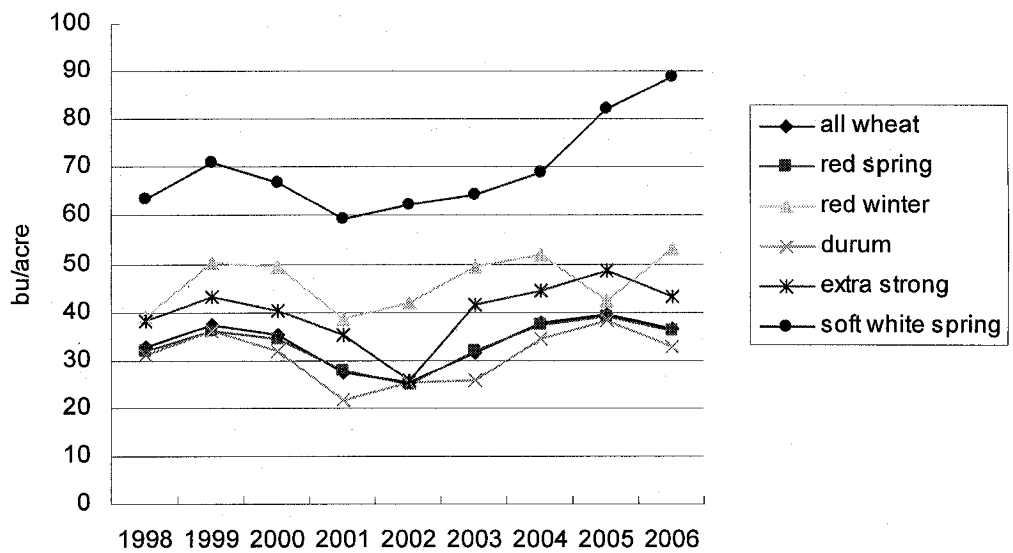

Figure 23: Annual Yield of Wheat in Western Canada (1998-2006)
Source: Statistics Canada (1998-2006)

4.2.2 Provincial Wheat Yield in Western Canada

Annual yields for the provincial data (British Columbia, Manitoba, Saskatchewan and Alberta) across wheat classes are regressed on the PBR variable and other explanatory variables including precipitation and temperature. Table 7 shows the results from the regression models estimated.

Table 7: Coefficient Estimates for Provincial Wheat Yields in Western Canada

Variable	Regression number			
	1	1'	2	2'
	Coefficient estimate [a]			
Acreage	0.001	0.001*	0.001	0.001*
	(1.82)	(2.35)	(1.85)	(2.34)
PBR area share as % of total area	0.054	0.054		
	(0.77)	(1.48)		
No. of PBR varieties as % of all varieties			7.659	7.659
			(0.94)	(1.83)
Price	-3.065	-3.065	-3.11	-3.11
	(-1.67)	(-1.79)	(-1.71)	(-1.85)
Precipitation (May to July)	0.014	0.014	0.012	0.012
	(0.62)	(0.54)	(0.51)	(0.44)
Temperature (May to August)	-0.008	-0.008	-0.008	-0.008
	(-1.11)	(-1.06)	(-1.18)	(-1.12)
British Columbia	7.881	7.881	7.238	7.238
	(1.23)	(1.71)	(1.22)	(1.66)
Manitoba	-2.780	-2.780	-2.88	-2.88
	(-1.08)	(-1.11)	(-1.11)	(-1.16)
Saskatchewan	-15.269**	-15.269**	-15.514**	-15.514**
	(-5.97)	(-5.38)	(-6)	(-5.39)
Red Spring	-18.03**	-18.03**	-17.649**	-17.649**
	(-2.66)	(-3.58)	(-2.97)	(-3.66)
Durum	-10.959*	-10.959*	-11.63*	-11.63**
	(-2.02)	(-2.58)	(-2.13)	(-2.75)
Soft White Spring	16.499**	16.499**	16.764**	16.764**
	(5.32)	(3.32)	(5.37)	(3.39)
Extra Strong	-5.825*	-5.825*	-6.032*	-6.032*
	(-2.1)	(-2.44)	(-2.16)	(-2.52)
Constant	72.726**	72.726**	73.82**	73.82**
	(4.86)	(4.99)	(4.98)	(5.12)

a * = 5 percent significance level; **= 1 percent significance level.
The t-statistics are in parentheses.

Regression 1 and 1' are based on the coefficient on the PBR area share variable (the share of acreage sown to varieties with Plant Breeders' Rights). As discussed in the methodology section, the unobservable effects across region and time in the pooled regression may not lead to constant variance of the error term. Consequently the Breusch-Pagan/ Cook-Weisberg test is employed to examine the problem of heteroskedasticity. Thus regression 1' is the robust heteroskedasticity correction of the model. Regression 2 is based on a different measure of PBR which is the number of PBR varieties as percent of all wheat varieties. This model specification indicated evidence of heteroskedasticity. Regression 2' is the robust correction of the model.

The results from regression 1' indicate the coefficient on the PBR area share variable is positive but not statistically significant at the 5 percent level of significance. This implies that wheat yields at the provincial level did not increase in response to the adoption of wheat varieties protected by Plant Breeders' Rights. The estimated coefficient of the acreage variable is positive and statistically significant at the 5 percent level of significance. The estimated coefficient of the price variable (producer price received from the previous year) is negative but not statistically significant at the 5 percent level of significance. The coefficient of the provincial dummy variable *Saskatchewan* is negative and statistically significant at the 1 percent level of significance which means, on average, the wheat yields in Saskatchewan are lower than the other provinces. The estimated coefficients of the wheat class dummy variables indicate that compared to the base wheat class Red Winter, the yields of Soft white Spring were higher, while in the other three wheat classes Red Spring, Durum and Extra Strong, yields were lower.

From regression 2', the coefficient of variable PBR number share is positive but not statistically significant at the 5 percent level of significance. This result indicates there is little impact of the proportion of all wheat varieties planted with

PBRs on wheat yields. The coefficient of variable *Saskatchewan* is negative and statistically significant at the 1 percent level of significance.

From both types of regression, coefficients of variables such as precipitation, and temperature are not significant. Thus, we can not tell whether these variables have an impact on wheat yields in western Canada during this period.

Overall, our results did not support that the PBR Act had a positive and statistically significant effect on wheat yields in western Canada. These results should be tested with caution as some fertilizer data was not included for all models estimated. Implications will be discussed later.

4.3 Results for Farm Reported Wheat Yields in Alberta

4.3.1 Variables and Regression Types

As mentioned previously, by investigating the impact of the PBR Act on wheat yields at lower level of aggregation would provide more robust conclusions. Moreover, the Alberta data allow us to analyze the different effects of the PBR Act on different wheat classes. Because there are many different wheat classes in western Canada and the size of breeders' market varies, an analysis by different wheat classes will provide a better understanding as to whether the impact of the PBR Act differs among wheat classes. The results in this section are based on wheat varieties in three wheat classes (Hard Red Spring, Durum and Prairie Spring wheat) that have been protected by Plant Breeders' Rights.

For the analysis in each wheat class, two measures of the impact of the PBR Act are employed in several regressions: the *PBR area share* (share of acres devoted to the variety if it has PBRs) and a dummy variable *PBR* (1= if the variety is protected by PBR, 0=otherwise).

Other explanatory variables included were fertilizer, precipitation and temperature variables. Four types of fertilizer, nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) are considered to be important for wheat growing and are included in the regression models. In addition, several qualitative variables are included in the regressions, including soil zone, variety and year.

For each wheat class model, wheat yields were regressed on the PBR variable, fertilizer variable and weather variables are included in each regression. Qualitative variables such as soil zone, year and variety, and interaction terms, were considered separately in order not to lose many degrees of freedom. Basically, after controlling for the effect of PBR, fertilizer input and climatic factors, regression 1 includes soil zone dummy variables to examine regional differences, regression 2 includes both soil zone and year dummy variables to examine the time and regional differences and regression 3 includes year dummy variables to examine time differences. Regression 4 included the interaction term of nitrogen and precipitation as previous studies found positive impact on wheat yield (Burt, 1995). Regression 5 includes the individual variety dummy variables as some varieties may be higher-yielding than others and thereby may influence the yield performance. Because of the multiple numbers of varieties in each wheat class some of them were combined together. Regression 6 includes the year dummy variables in order to examine time, regional and varietal differences.

The results show that the PBR Act had a positive effect on wheat yields for the Durum wheat class model. For the other two wheat classes, the effect of the PBR Act was not positively associated with increasing wheat yields (Appendix A for Hard Red Spring wheat and Appendix B for Prairie Spring wheat).

4.3.2 Results for Durum Wheat

Table 8 and Table 9 show the results from the regression models estimated.

Table 8: Coefficient Estimates for Durum Wheat Yield with PBR Area Share

Variable	Regression number 1	2	3	4	5	6
			Coefficient estimate [a]			
PBR area share	37.358**	37.358**	37.358**	37.358**	16.695	16.695
	(3.59)	(3.59)	(3.59)	(3.59)	(1.24)	(1.24)
Nitrogen	-1.305**	-1.308**	-0.856	-3.786*	-1.312**	-1.332**
	(-3.28)	(-3.09)	(-1.37)	(-2.47)	(-3.82)	(-3.64)
Phosphorus	-7.223**	-7.021**	-6.308**	-7.62**	-7.031**	-5.083**
	(-3.71)	(-4.48)	(-2.86)	(-2.66)	(-4.18)	(-3.09)
Potassium	7.1817**	7.0952**	5.5027*	0.1247	7.1268**	6.29**
	(5.39)	(6.61)	(2.57)	(0.44)	(6.18)	(6.17)
Sulphur	-37.79**	-36.97**	-30.88*		-37**	-29.101**
	(-4.42)	(-4.63)	(-2.51)		(-4.99)	(-3.65)
Precipitation	0.194**	0.1892**	0.1896**	-0.824	0.1874**	0.141**
	(3.29)	(4.35)	(4.37)	(-1.94)	(3.67)	(3.19)
Temperature	-0.32**	-0.318**	-0.25**	-0.361**	-0.321**	-0.302**
	(-6.34)	(-9.74)	(-2.88)	(-2.86)	(-7.36)	(-9.96)
N*P				0.0175*		
				(2.21)		
Brown	-1.585				-15.31	
	(-0.07)				(-0.75)	
Dark brown	-6.268	-5.498		18.435*	-21.56	-14.124*
	(-0.41)	(-0.86)		(2.39)	(-1.45)	(-2.17)
2000		0.681	-5.214			6.578
		(0.07)	(-0.64)			(0.75)
2002			-9.79	-27.27**		
			(-0.86)	(-4.18)		
AC Morse					-1.654	-1.654
					(-0.59)	(-0.59)
AC Navigator					5.215	5.215
					(1.59)	(1.59)
Kyle					-4.686	-4.686
					(-1.37)	(-1.37)
Other					-5.315	-5.315
					(-1.76)	(-1.76)
Constant	674.37**	665.84**	537.41**	816.37**	691**	608.635**
	(4.91)	(9.78)	(2.94)	(2.77)	(5.83)	(9.07)
Observations	66	66	66	66	66	66
R-square Adj	0.83	0.83	0.83	0.83	0.88	.88

Regression 1: soil zone dummy variables;
Regression 2: both soil zone and year dummy variables;
Regression 3: year dummy variables;
Regression 4: interaction term nitrogen*precipitation, soil zone and year dummy variables;
Regression 5: soil zone dummy variables and variety dummy variables;
Regression 6: soil zone dummy, year dummy and variety dummy variables.
a * = 5 percent significance level; **= 1 percent significance level.
The t-statistics are in parentheses.

Note: AC Morse, AC Navigator, AC Avonlea and Other are the variety dummy variables and AC Avonlea is the base variety which is omitted in the estimation to avoid collinearity.

Table 9: Coefficient Estimates for Durum Wheat Yields with PBR

Variable	Regression numbers 1	2	3	4
	Coefficient estimate [a]			
PBR	7.546**	7.546**	7.546**	7.546**
	(5.68)	(5.68)	(5.68)	(5.68)
Nitrogen	-1.296**	0.324	-1.34**	-0.93
	(-3.69)	(0.72)	(-3.57)	(-0.89)
Phosphorus	-6.891**	-0.576	-3.2**	-1.838
	(-4.01)	-0.55	(-4.01)	(-0.99)
Potassium	6.979**	-0.462	5.393**	0.551*
	(5.94)	(-0.51)	(6.77)	(2.56)
Sulphur	-35.73**	1.635	-20.8**	
	(-4.74)	(0.29)	(-4.09)	
Precipitation	0.183**	0.096**	0.094**	-0.125
	(3.52)	(3.62)	(3.58)	(-0.4)
Temperature	-0.313**	-0.027	-0.28**	-0.143
	(-7.05)	(-0.61)	(-11)	(-1.6)
Nitrogen*precipitation				0.004
				(0.67)
Brown	-29.02			
	(-1.61)			
Dark brown	-34.31**		-20.2**	-3.527
	(-3.13)		(-5.06)	(-1.22)
2000		-9.205	12.47	
		(-1.28)	(1.61)	
2002		-36**		-26.38**
		(-5.06)		(-4.58)
Constant	683.4**	55.11	527.3**	291.5
	(5.63)	(0.64)	(12.77)	(1.41)
Observations	66	66	66	66
R-square Adj	0.87	0.87	0.87	0.87

Regression 1: soil zone dummy variables;

Regression 2: both soil zone and year dummy variables;

Regression 3: year dummy variables;

Regression 4: interaction term nitrogen*precipitation, soil zone and year dummy variables;

a * = 5 percent significance level; **= 1 percent significance level.

The t-statistics are in parentheses.

According to Table 8 and Table 9, the impact of the PBR Act on Durum wheat yield is positive and significant. The estimated coefficient of the PBR area share variable is positive and statistically significant at the 1 percent level of significance. On average, an additional 1 percent increase in acreage sown to PBR varieties would increase Durum wheat yields by 0.374 bu/acre. Similarly, the coefficient of the PBR dummy variable is positive and statistically significant at the 1 percent level of significance. This implies that if a wheat variety is protected by PBR rights, on average, the yield would be higher by 7.546 bu/acre. These results indicate that the PBR Act has increased the yield of Durum wheat.

The effects for different fertilizers on Durum wheat yields varied. The increased quantity of nitrogen, phosphorus and fertilizer sulphur did not increase Durum wheat yields. Potassium was the only fertilizer that has positive and significant impact on Durum wheat yields. Sulphur is considered to be deficient in most soil zones in Alberta, but only brown and dark brown soil zones are considered not to be deficient in S. The relatively rich fertilizer of S in brown and dark brown soil zones may explain the insignificant effect of the sulphur application rate on wheat yields.

The estimated coefficient on the *precipitation* variable was found to be positive and statistically significant at the 1 percent level of significance. On the other hand, the estimated coefficient on the *temperature* variable is negative and statistically significant at the 1 percent level of significance. This result is consistent with as Campbell et al. (1997b) who found air temperature in Saskatchewan and Alberta was negatively associated with Hard Red Spring wheat yields. It is possible that higher temperatures may cause more soil moisture deficiencies during the growing season which is more important than excessive precipitation as a yield determinant (Feyerherm and Paulsen, 1981).

Because of few observations, many soil zone dummy variables had to be deleted from the sample. The coefficients of brown and dark brown soil zones are not statistically significant. Similarly, the coefficients for the year 2000 and 2002 are not statistically significant as well. The coefficient of the interaction term of nitrogen and precipitation is positive and statistically significant at the 1 percent level of significance. Burt (1995) estimated a positive relation between nitrogen fertilizer and moisture except when moisture was scarce or excessive.

From the regression 5 and 6 in Table 8, none of the variety dummy variables are statistically significant, while the variety dummy variables of Table 9 are omitted in the thesis as variable *PBR* is dropped automatically in STATA due to collinearity in their regressions.

In sum, our results support the hypothesis that the PBR Act increased the yields for Durum wheat. On the other hand, our analysis of Hard Red Spring wheat and Prairie Spring wheat in Alberta indicates that the PBR Act did not help to increase the wheat yields as both variable *PBR share area* and *PBR* are not significant at the 5 percent level of significance. Since Durum wheat comprises a small share of production and area of all wheat in Alberta, the PBR Act seems to have a relatively small impact on wheat yields.

4.4 Discussion

4.4.1 Wheat Yields in Western Canada

The Plant Breeders' Rights Act in Canada was expected to have increased wheat yields. The finding that the PBR Act did not have a positive and statistically significant impact on overall wheat yields in western Canada is surprising considering one would have expected the PBR Act would induce more R&D investment in plant breeding and thereby introducing more varieties with higher productivity. Yet there exist several reasons to explain this result.

First, it is possible that the PBR Act may have different impacts on different classes as breeders' markets vary (it is confirmed from the results of the Alberta wheat yield). Yet from our small sample, as explained before, it is not possible to analyze by class and we can only analyze the impact across the different classes. So the results may not precisely reflect the actual impact of the PBR Act on different wheat classes. In the U.S., Alston and Venner (2002) did a similar study by quantifying the effects of the U.S. Plant Variety Protection Act (PVPA) on commercial wheat yields by class and they found the PVPA did not contribute to the commercial yields of Hard Red Spring and Hard Red Winter wheat. Similarly, other studies investigated different crops in different places and most of results showed PVP or PBR did not have much effect on crop yields (Perrin et al. 1983; Babcock and Foster 1991, Carew and Devadoss 2003).

Second, the data are only for 9 years and it prevents us from performing a trend analysis as to whether the PBR Act in Canada lead to a structural break of wheat yields as most other studies did. Since our data can not tell whether there is a structural break of wheat yields, it may not reflect the actual impact.

Third, it is known that production input factors, environment and climate factors are very important to wheat yields, especially nitrogen, phosphate, potassium and sulphur. Given the aggregate nature of our data, we are unable to control for these factors. Even if we have the precipitation and temperature data to account for climatic factors, other environmental factors such as soil quality, insect pressure and management practices influence on wheat yields. Without controlling these factors, our results may not reflect the actual effect of the PBR Act on wheat yields.

Last but not least, the purpose of implementing the PBR Act is to induce the increase of R&D research for crop breeding so that more varieties with higher productivity will be available. However output per unit (yield) is just one measure of productivity, other measures include better quality and better resistance to insects. Thus it is likely that there is a trade-off between yield and quality so that new PBR varieties may have better quality traits but not higher yields. Farmers may have planted more wheat varieties with better quality but not higher yields. Since our study focused on the impact on yields, important implications for future research may focus on the impact of PBR on wheat quality improvement. In this context, many countries especially some developing countries have implemented the PBR policy not only expecting to improve crop yields, but also crop quality (Hu et al., 2006).

Therefore, the results for western Canada are not rigorous enough and we should treat the results carefully.

4.4.2 Wheat Yields in Alberta

Our results for different classes of wheat in Alberta indicate that the PBR Act has increased yields for Durum wheat, but did not have a positive impact on Hard Red Spring wheat and Prairie Spring wheat. It confirms our hypotheses that the PBR Act had different impacts on different wheat classes. Since the size of the breeders' seed market varies between wheat classes, our results show that the impact of Plant breeders' right differed by market size.

For Durum wheat, 14 varieties were planted in Alberta from 1999 to 2003, only 3 were protected with PBR rights (AC Avonlea, AC Morse and AC Navigator). From our results, these varieties are higher yielding than other non protected varieties. In 2006, besides the above varieties, 3 new varieties with PBR rights were planted in

Alberta (Napoleon, Strongfield and Commander) and the numbers of none protected varieties decreased. This is further evidence that farmers have a tendency to plant more varieties with PBR rights for Durum wheat as the protected varieties were higher yielding.

Though the PBR Act increased the yields for Durum wheat, it did not have an impact on yields for Hard Red Spring and Prairie Spring wheat, which may mitigate the importance of obtaining PBR rights for intellectual property protection since Hard Red Spring wheat has about 70% production and acreage of all wheat but the protected varieties are not higher-yielding. Our results also indicated that the PBR Act had a relatively small impact on wheat productivity since the market for Durum wheat is about 20% of the Hard Red Spring wheat market.

Care should be taken in interpreting our results. First, the results of the PBR Act impact on Durum wheat yields are only from Alberta from 1999 to 2003, while the impact on the other two Durum wheat producing provinces, Saskatchewan and Manitoba are not clear. Moreover, as the production and acreage of Durum wheat in Saskatchewan is about 80% in western Canada (see Figure12), we can not conclude that the impact of the PBR Act in Saskatchewan is the same as in Alberta since some planting conditions vary across regions. Further studies may investigate the circumstances in Saskatchewan and Manitoba. Second, our data are only for 5 years, which prevents us from performing trend analysis. Third, until 2003, there were no varieties protected with PBRs in the class of Hard Red Winter which prevents from analyzing the impact of the PBR Act on this class. Yet until 2006 two PBR varieties (Radiant and McClintock) were planted in Alberta and other western provinces. As we have mentioned before, the numbers and acreage of varieties with PBR rights are increasing, further studies can examine the impact with more updated data in order to understand better about the impact of the PBR Act.

Chapter 5: Conclusions

5.1 Conclusions

Plant Breeders' Rights (PBR) are a form of intellectual property rights enabling breeders of new varieties of plants to have the exclusive right to produce and sell propagating material of their new plant varieties. Canada passed its PBR Act in 1990 with the objective of encouraging firms to undertake R&D, technology transfer and commercialization of superior varieties. In order to examine the achievements of the PBR regime during the past ten years, a review by the Canadian Food Inspection Agency (CFIA) published in 2001 found the results of PBR Act to be generally positive. However, given the subjective nature of the analysis, the review was not rigorous enough to be conclusive. This study was motivated by the lack of empirical research of the impact of PBR Act on crop productivity in Canada and wheat was selected as a case for study.

There are two main objective of this study: first, to examine the relationship between the PBR Act and provincial wheat yields in western Canada; second, to examine the relationship between the PBR Act and individual wheat variety yields in different classes in Alberta. Yield response function methods were employed to test the hypothesis that adoption of the PBR Act led to an increase in overall wheat yields and rate of yield increase.

For the provincial wheat yields in western Canada, a period from 1998 to 2006 was examined with our empirical yield response function model. Our results show that the PBR Act did not have a significant effect on overall wheat yields in western Canada. The coefficient of the PBR area share variable (the share of wheat acreage sown to varieties with PBR rights) is positive but not statistically significant at the 5 percent level of significance. The other PBR number share variable (number of

PBR varieties as a percent of all varieties) is positive but not statistically significant at the 5 percent level of significance as well. The insignificant results of the PBR Act impact should be interpreted with some caution for a number of reasons. First, our western Canada observation is relatively small for all wheat yields and does not account for differences in wheat classes. Since the PBR Act may have different impacts on different wheat classes, the results may not reflect the actual impact. Second, due to the limitation of data, our study did not conduct structural break and yield trend analysis. Without controlling for trend effects, the results may not reflect the actual impact. Third, given the aggregate nature of the data, we are unable to control for some important factors such as fertilizer rate, soil quality, which may lead to the error in the results. Fourth, it is still possible that the PBR Act had a positive and significant impact as productivity of wheat yields increased but in other forms such as wheat quality improvements. Since productivity can be measured such as the yielding ability, pest-resistance and quality traits, it is possible that the trade-off between yield and quality exists. Farmers may have planted more wheat varieties with better quality.

For the farm reported wheat variety yields in Alberta, a period from 1999 to 2003 was examined in the eight soil zones with the empirical yield response function model. The impact of the PBR Act was tested in three different classes of wheat: Durum wheat, Hard Red Spring wheat and Prairie Spring wheat.

For Durum wheat, the signs and significance for the two PBR variables are consistent. Both of them are positive and statistically significant at the 1 percent level of significance. With PBR area share variable, on average, an additional 1 percent increase of acreage sown to varieties with PBR rights would have increased the Durum wheat yields by 0.374 bu/acre. With PBR dummy variable, on average, the yield of a variety protected with PBR rights is higher than those non protected varieties by 7.546 bu/acre. However, for Hard Red Spring wheat and Prairie Spring wheat, the two PBR Act variables are positive but neither is statistically significant at the 5 percent level of significance.

The impacts of four types of fertilizer are different for the three classes. For Durum wheat, the impacts of nitrogen (N), phosphorus (P) and sulphur (S) are negative and statistically significant while the impact of potassium (K) is positive and statistically significant. For Hard Red Spring wheat, the impacts of four types of fertilizer (N, P, K and S) on yields are positive and statistically significant. For prairie spring wheat, only the effects of fertilizer K are positive and statistically significant.

With regard to climate impact, the coefficients of the variable *precipitation* are positive and statistically significant while the coefficients of variable *temperature* are negative and statistically significant for Durum and Hard Red Spring wheat. Yet for Prairie Spring wheat, the coefficients of variable *precipitation* and *temperature* are not statistically significant, indicating climate factors are not closely related to prairie spring wheat yields.

In sum, the results of Alberta reveal that the PBR Act had a positive and significant impact on Durum wheat yields while it did not have an impact on both Hard Red Spring wheat and Prairie Spring wheat. As we have discussed before, the market of Durum wheat is only about 20% of the Hard Red Spring wheat market, which may mitigate the importance of obtaining PBR rights for intellectual property protection. More over, there are limitations from our study. First, our positive result for Durum wheat is only from Alberta, which is the relatively small market compared to that of Saskatchewan. There is need to replicate such kind of study in other provinces to verify the results. Second, our data ends in 2003, which prevents us from performing trend analysis and from analyzing more updated data on other classes of wheat such as Hard Red Winter.

Overall, our results from western Canada and Alberta indicate that the PBR Act had a relatively small impact on wheat yields, which is consistent with the study of Alston and Venner (2002). The results do not support the hypothesis that the adoption of the PBR Act led to the increase of overall wheat yields and rate of yield increase is higher in classes whose varieties are protected with Plant Breeders' Rights[1].

5.2 Policy implications

The finding that the PBR Act has not increased productivity of wheat suggests there is a need to improve the design of the PBR regime in Canada. Venner (1997) pointed out as an open-pollinated crop, the genotypes of wheat remained unchanged across generations so growers can save the seeds from the previous harvest according to the "farmers' privilege". Therefore, the inventors or breeders could only appropriate the returns of their innovation partially and thereby reduce the incentive for R&D. On the other hand, the "farmers' privilege" is not stated in the current Act in Canada. With the current Canadian PBR Act, it would not exempt farmers from obtaining authorization from the holder of the rights before they sell seed produced from a protected variety as a seed for planting. This has weakened the intellectual property protection for breeders and may further reduce the return of the rents for them.

Improvement of the design of the PBR regime could encourage private sectors to develop advanced varieties of open-pollinated crops. First, Canada operates a PBR application system with examinations conducted by the applicant under government supervision, which is similar as that of EU, yet it is costly in

[1] Since all the three classes of wheat in Alberta have varieties protected with PBR rights, only the impact of the PBR Act on Durum is positive and significant.

administration and delay and thereby reduces the availability and accessibility of new varieties[1]. Perhaps an effective hybrid system would be the US registration process with higher distinctness standards. US registration system is different as no variety testing is undertaken and distinctness can be established in any dimensions (Lesser, 2000). With a high standard of distinctness, such as defining distinctness among varieties by economic value based on performance in experimental trials, the PBR system will be more effective (Venner (1997) discusses a detailed method). Second, Canada should amend the PBR Act in conformity to the 1991 UPOV Convention as proposed from different industries to strengthen the intellectual property protection in term of restricting the "farms' privilege" and "breeders' exemption". Regarding "farmers' privilege", the experience of EU (require owners of large farms to pay royalties on saved seed) should be feasible. With regard to "breeders' exemption", a phased-in breeder's exemption (limit this provision from becoming active until a certain years of protection have passed) would enhance the rights of breeders (Eaton, 2006). Third, since previous study (Carew and Devadoss, 2003) and our study found different impacts of PBR Act on different crops (canola and wheat), policy makers should take into account it and design different and more specific PBR measures respectively for these different types of crops in order to better take advantage of the PBR system.

Other policy options include use of a contract with farmers that develop open pollinated varieties. Agreements can stipulate that farmers will not replant harvested seed without permission of the breeders and thereby secure intellectual property rights to a plant variety innovation on the part of breeders.

[1] In Europe, commodity committees are responsible for identifying relevant attributes for protection and in some case to establish a minimum statistical standard for meeting that requirement compared to the reference variety. Growout trials are undertaken to measure performance in field conditions. (Lesser, 2000)

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Appendix A: Results for Hard Red Spring Wheat in Alberta

TableA 1: Coefficient Estimates for Hard Red Spring Wheat Yield with PBR Area Share

Variable	Regression number					
	1	2	3	4	5	6
	Coefficient estimate [a]					
PBR area share	5.113	7.866	8.942	7.87	13.814	17.04
	(0.63)	(1.45)	(1.4)	(1.55)	(1.03)	(1.93)
Nitrogen	-0.278**	0.382**	0.239**	1.032**	-0.284**	0.373**
	(-2.64)	(4.46)	(3.01)	(8.14)	(-2.67)	(4.39)
Phosphorus	0.192	0.518*	0.273	1.502**	0.173	0.493*
	(0.81)	(2.50)	(1.34)	(6.15)	(0.72)	(2.39)
Potassium	0.371*	0.799**	0.311*	1.161**	0.365*	0.791**
	(2.28)	(5.29)	(2.45)	(7.67)	(2.24)	(5.31)
Sulphur	1.579**	0.531	-0.166	2.011**	1.555**	0.476
	(4.47)	(1.63)	(-0.54)	(5.32)	(4.35)	(1.46)
Precipitation	-0.028**	-0.003	0.04**	0.352**	-0.028**	-0.002
	(-3.02)	(-0.35)	(6.13)	(6.50)	(-2.98)	(-0.23)
Temperature	-0.08**	-0.064**	-0.008	-0.01	-0.081**	-0.064**
	(-7.81)	(-4.75)	(-0.8)	(-0.65)	(-7.79)	(-4.82)
2000		-1.355	-5.868**	2.29		-1.501
		-0.88	(-3.86)	(1.49)		(-0.99)
2001		6.632*	-7.216**	6.715*		6.381*
		(2.15)	(-3.62)	(2.33)		(2.09)
2002		-20.754**	-25.788**	-24.812**		-21.022**
		(-11.40)	(-14.35)	(-13.71)		(-11.66)
2003		1.268	-2.356	-9.879**		1.154
		0.43	(-0.95)	(-3.05)		(0.39)
Nitrogen*precipitation				-0.007**		
				(-6.62)		
black	1.245	17.216**		-6.973	0.724	-17.578**
	(0.27)	(-4.15)		(-1.67)	(0.15)	(-4.27)
dark brown	-12.993**	-22.807**		16.008**	-12.845**	-22.471**
	(-3.95)	(-7.51)		(5.30)	(-3.88)	(-7.48)
gray	-29.394**	-54.937**		-39.524**	-29.538**	-54.488**
	(-4.18)	(-7.26)		(-5.31)	(-4.16)	(-7.25)
peace river	-17.54**	-38.162**		-21.781**	-17.1**	-37.349**
	(-3.47)	(-6.51)		(-3.62)	(-3.36)	(-6.44)
AC Eatonia					2.092	1.944

TableA1 (cont.) Coefficient Estimates for Hard Red Spring Wheat with PBR Area Share

	Regression number					
Variable	1	2	3	4	5	6
	Coefficient estimate [a]					
					(-0.46)	(0.66)
AC Intrepid					4.644	6.625**
					(1.31)	(2.87)
AC Splendor					6.069	6.437*
					(1.41)	(2.3)
CDC Teal					5.12	5.536*
					(1.26)	(2.08)
Roblin					1.97	1.842
					(0.46)	(0.66)
Other					2.894	3.515
					(0.84)	(1.55)
Constant	146.678**	99.44**	23.197	-34.232	144.959**	96.866**
	(7.61)	(4.37)	(1.22)	(1.17)	(7.28)	(4.26)
Observations	312	312	312	312	312	312
R-squared Adj	0.53	0.79	0.71	0.82	0.55	0.8

Regression 1: soil zone dummy variables;

Regression 2: both soil zone and year dummy variables;

Regression 3: year dummy variables;

Regression 4: interaction term nitrogen*precipitation, soil zone and year dummy variables;

Regression 5: soil zone dummy variables and variety dummy variables;

Regression 6: soil zone dummy variable, year dummy variables and variety dummy variables.

a * =5 percent significance level; **=1 percent significance level.

The t-statistics are in parentheses.

TableA 2: Coefficient Estimates for Hard Red Spring Wheat Yields with PBR

	Regression number					
Variable	1	2	3	4	5	6
			Coefficient estimate [a]			
PBR	0.468	1.094	1.17	1.059	0.563	1.092
	(0.38)	(1.33)	(1.2)	(1.38)	(0.33)	(0.98)
Nitrogen	0.282**	0.373**	0.238**	1.021**	-0.293**	0.357**
	(2.67)	(4.35)	(2.99)	(8.06)	(-2.75)	(4.20)
Phosphorus	0.186	0.499*	0.28	1.482**	0.16	0.458*
	(0.79)	(2.40)	(1.37)	(6.06)	(0.67)	(2.21)
Potassium	0.37*	0.786*	0.323*	1.147**	0.366*	0.773**
	(2.27)	(5.20)	(2.56)	(7.57)	(2.24)	(5.16)
Sulphur	1.576**	0.503	-0.154	1.982**	1.549**	0.43
	(4.46)	(1.54)	(-0.5)	(5.24)	(4.33)	(1.32)
Precipitation	-0.028**	-0.003	0.04**	0.351**	-0.028**	-0.002
	(-3.05)	(-0.33)	(6.12)	(6.49)	(-3.01)	(-0.2)
Temperature	-0.08**	-0.065**	-0.008	-0.011	-0.081**	-0.066**
	(-7.84)	(-4.80)	(-0.78)	(-0.71)	(-7.85)	(-4.91)
Black	1.429	-16.779**		-6.549	1.007	-17.003**
	(0.31)	(-4.05)		(-1.57)	(0.21)	(-4.12)
Dark brown	-12.982**	-22.685**		-15.895**	-12.784**	-22.281**
	(-3.94)	(-7.47)		(-5.26)	(-3.86)	(-7.38)
Grey	-29.195**	-54.128**		-38.74**	-29.238**	-53.406**
	(-4.15)	(-7.17)		(-5.21)	(-4.12)	(-7.09)
Peace river	-17.554**	-37.88**		-21.525**	-17.136**	-37.053**
	(-3.47)	(-6.46)		(-3.58)	(-3.36)	(-6.36)
2000		-1.395	-6**	2.243		-1.547
		(-0.91)	(-3.95)	(1.46)		(-1.02)
2001		6.529*	-7.41**	6.612*		6.316*
		(2.11)	(-3.73)	(2.29)		(2.06)
2002		-20.773**	-25.964**	-24.824**		-20.968**
		(-11.40)	(-14.46)	(-13.71)		(-11.57)
2003		1.407	-2.573	-9.726**		1.48
		(0.47)	(-1.04)	(-3.00)		(0.5)
Nitrogen* precipitation				-0.007**		
				(-6.60)		
AC Eatonia					0.534	0.047
					(0.13)	(0.02)

TableA2 (cont.): Coefficient Estimates for Hard Red Spring Wheat with PBR						
	Regression number					
Variable	1	2	3	4	5	6
	Coefficient estimate [a]					
AC Intrepid					3.222	4.9*
					(0.99)	(2.29)
AC Splendor					3.775	4.026
					(1.02)	(1.67)
CDC Teal					2.865	3.149
					(0.83)	(1.39)
Roblin					-0.258	-0.515
					(-0.07)	(-0.21)
other					0.657	1.097
					(0.25)	(0.63)
Constant	147.537**	101.067**	22.793	-32.431	148.78**	102.369**
	(7.66)	(4.44)	(1.2)	(1.11)	(7.60)	(4.52)
Observations	312	312	312	312	312	312
R-squared Adj	0.53	0.79	0.71	0.82	0.53	0.8

Regression 1: soil zone dummy variables;
Regression 2: both soil zone and year dummy variables;
Regression 3: year dummy variables;
Regression 4: interaction term nitrogen*precipitation, soil zone and year dummy variables;
Regression 5: soil zone dummy variables and variety dummy variables;
Regression 6: soil zone dummy variable, year dummy variables and variety dummy variables.
a * = 5 percent significance level; **= 1 percent significance level.
The t-statistics are in parentheses.

According to the regressions on the two PBR variables, the PBR Act did not increase the yields for Hard Red Spring wheat. The coefficients of the variable *PBR area share* and *PBR* are positive but none of them are statistically significant at the 5 percent level of significance.

The four types of fertilizer, nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) are considered to be important for wheat growing. From TableA1 and A2, most coefficients of *N* are positive and statistically significant. The coefficients of P are positive and statistically significant, reflecting the importance of P on wheat yields. Adequate K results in superior quality of the whole plant and our result indicates that the amount of K used increases wheat yields as the coefficients of *K* are positive and statistically significant. S is considered to be deficient in most soil zones in Alberta, only brown and dark brown soil zones are considered not to be deficient in S. Our analysis shows that the use of S increases wheat yields.

The estimated coefficients on the variable *precipitation* that represents precipitation in the wheat growing season are positive and statistically significant at the 1 percent level of significance. On the other hand, the estimated coefficients on the variable *temperature* that represents air temperature in wheat growing season are negative and statistically significant at the 1 percent level of significance.

For soil zone dummy variables, black dark gray west, brown and thin black soil zone dummies were dropped due to no fertilizer data in these soil zones. The estimated coefficients of the other soil zone varieties are negative and most of them are statistically significant. For the year dummies, the coefficients of the year dummy variable *2002* are negative and statistically significant in all regression, which means Hard Red Spring wheat yield in 2002 was much lower than in other years. In the regressions of both Tables, the interaction term of nitrogen and precipitation is included but the estimated coefficient is negative and statistically significant, yet the influence is very small.

In regression 5 and regression 6, individual variety dummy variables are included, however, only the coefficient of the variety *AC Intrepid* (it has PBRs) is positive and statistically significant at 5 percent level of significance. For other varieties, none of the estimated coefficients are significant.

In sum, our analysis of the Hard Red Spring wheat in Alberta indicates the PBR Act did not help to increase the wheat yields as both variable *PBR share area* and *PBR* are not significant at 5 percent level of significance.

Appendix B: Results for Prairie Spring Wheat in Alberta

TableB 1: Coefficient Estimates for Prairie Spring Wheat Yield with PBR Area Share

	Regression number					
Variable	1	2	3	4	5	6
	Coefficient estimate [a]					
PBR area share	-0.486	7.725	9.117	7.831	-35.38	-2.963
	(-0.04)	(1.07)	(1.21)	(1.08)	(-1.49)	(-0.2)
Nitrogen	-0.988**	0.261	0.884**	0.462	-0.902*	0.291
	(-2.69)	(1.05)	(3.76)	(0.99)	(-2.45)	(1.19)
Phosphorus	0.542	1.372**	0.287	1.51**	0.4777	1.284*
	(0.86)	(2.7)	(0.58)	(2.61)	(0.76)	(2.54)
Potassium	0.097	1.489**	0.93**	1.634**	0.3605	1.53**
	(0.17)	(3.44)	(2.78)	(3.14)	(0.6)	(3.58)
Sulphur	1.837*	1.041	-1.66*	1.289	1.6764	0.881
	(2.01)	(1.33)	(-2.46)	(1.39)	(1.84)	(1.13)
Precipitation	-0.021	-0.01	0.076**	0.073	-0.017	-0.01
	(-0.71)	(-0.6)	(5.35)	(0.43)	(-0.59)	(-0.46)
Temperature	-0.075*	0.007	0.054	0.014	-0.065	0.007
	(-2.12)	(0.2)	(1.87)	(0.36)	(-1.82)	(0.21)
Nitrogen* precipitation				0		
				(-0.51)		
Black	48.82**	24.68		23.9	47.491*	22.529
	(2.61)	(1.81)		(1.74)	(2.52)	(1.67)
Dark brown	22.68	12.46		11.66	24.728	12.613
	(1.47)	(1.13)		(1.04)	(1.58)	(1.15)
Grey	15.74	-16.4		-17.6	12.266	19.116
	(0.57)	(-0.74)		(-0.79)	(0.45)	(0.88)
Peace river	28.98	6.071		5.688	29.549	4.585
	(1.36)	(0.34)		(0.31)	(1.37)	(0.26)
AC Foremost					-9.106	1.579
					(-0.94)	(0.27)
AC Taber					-15.84	-5.81
					(-1.67)	(-1.02)
Biggar					-15.36	-5.22
					(-1.59)	(-0.9)
Other					-17.77	-6.847
					(-1.93)	(-1.23)
2000		-14.2**	-11.9*	-12.8*		-14.08**
		(-3.39)	(-2.15)	(-2.5)		(-3.42)

Table B1 (cont.): Coefficient Estimates for Prairie Spring Wheat with PBR Area Share

	Regression number					
Variable	1	2	3	4	5	6
	Coefficient estimate [a]					
2001		-8.94	-13.7*	-7.9		-8.386
		(-1.23)	(-2.12)	(-1.05)		(-1.18)
2002		-43.8**	-43.2**	-44.6**		-43.055**
		(-9.88)	(-8.22)	(-9.38)		(-9.72)
2003		-19.1*	-2.92	-20.9*		-17.675*
		(-2.44)	(-0.41)	(-2.42)		(-2.26)
Constant	140.9*	-16.1	-76.3	-38.1	138.66*	-10.935
	(2.3)	(-0.28)	(-1.53)	(-0.52)	(2.27)	(-0.19)
Observations	88	88	88	88	88	88
R-square Adj	0.31	0.76	0.69	0.75	0.32	0.77

Regression 1 : soil zone dummy variables;

Regression 2: both soil zone and year dummy variables;

Regression 3: year dummy variables with robust correct for heteroskedasticity;

Regression 4: interaction term nitrogen*precipitation, soil zone and year dummy variables;

Regression 5: soil zone dummy variables and variety dummy variables;

Regression 6: soil zone dummy variable, year dummy variables and variety dummy variables.

a * = 5 percent significance level; **= 1 percent significance level.

The t-statistics are in parentheses.

TableB 2: Coefficient Estimates for Prairie Spring Wheat Yields with PBR

Variable	Regression number				
	1	2	3	4	5
			coefficient estimate [a]		
PBR	4.47	3.94	3.93	4.02897	12.82
	(1.13)	(1.68)	(1.45)	(1.7)	(1.64)
Nitrogen	-0.98**	0.27	0.9**	0.4976	-0.941
	(-2.7)	(1.09)	(3.83)	(1.07)	(-2.58)
Phosphorus	0.48	1.31	0.23	1.467*	0.423
	(0.76)	(2.6)	(0.49)	(2.56)	(0.67)
Potassium	0.09	1.51**	0.97**	1.67786**	0.093
	(0.16)	(3.54)	(2.9)	(3.26)	(0.16)
Sulphur	1.77	0.96	-1.74**	1.24303	1.672
	(1.96)	(1.24)	(-2.66)	(1.36)	(1.84)
Precipitation	-0.02	-0.01	0.08**	0.08774	-0.012
	(-0.63)	(-0.52)	(5.43)	(0.52)	(-0.42)
Temperature	-0.08*	0	0.05	0.01269	-0.073*
	(-2.23)	(0.14)	(1.84)	(0.34)	(-2.1)
Nitrogen*precipitation				-0.0019	
				(-0.59)	
Black	47.9*	23.8		22.8672	48.43*
	(2.58)	(1.77)		(1.68)	(2.57)
Dark brown	20.6	10.7		9.75094	21.32
	(1.34)	(0.97)		(0.87)	(1.36)
Grey	15.2	-17.5		-19.032	14.73
	(0.56)	(-0.8)		(-0.86)	(0.54)
Peace river	28	4.95		4.48665	29.11
	(1.32)	(0.28)		(0.25)	(1.36)
AC Foremost					14.39
					(1.5)
AC Taber					8.466
					(0.89)
Biggar					8.651
					(0.88)
Other					-0.438
					(-0.07)
2000		-13.8**	-11.5*	-12.075*	
		(-3.32)	(-2.11)	(-2.39)	
2001		-8.1	-12.7*	-6.9017	
		(-1.13)	(-2.03)	(-0.92)	
2002		-43**	-42.6**	-43.999**	

TableB2 (cont.): Coefficient Estimates for Prairie Spring Wheat Yields with PBR

Variable	1	2	3	4	5
		Coefficient estimate [a]			
		(-9.86)	(-8.07)	(-9.4)	
2003		-18.2*	-2.1	-20.246*	
		(-2.35)	(-0.31)	(-2.37)	
Constant	144*	-12.8	-76.3	-38.038	128.6*
	(2.39)	(-0.22)	(-1.52)	(-0.53)	(2.09)
Observations	88	88	88	88	88
R-square Adj	0.32	0.76	0.69	0.76	0.32

Regression 1: soil zone dummy variables;
Regression 2: both soil zone and year dummy variables;
Regression 3: year dummy variables with robust correct for heteroskedasticity;
Regression 4: interaction term nitrogen*precipitation, soil zone and year dummy variables;
Regression 5: soil zone dummy variables and variety dummy variables;
a * = 5 percent significance level; **= 1 percent significance level.
The t-statistics are in parentheses.

Prairie Spring Wheat includes Prairie Spring White Wheat and Prairie Spring Red Wheat, our data includes both. From the results of both Tables, PBR Act did not increase the yield for Prairie Spring Wheat. The estimated coefficients of the variable *PBR area share* and *PBR* are not statistically significant. Likewise, the coefficients of the dummy variable PBR are not significant.

For the fertilizer variables, the coefficients of fertilizer *N, P* and *S* are not positive and statistically significant while the coefficients of fertilizer *K* are positive and statistically significant at the 1 percent level of significance. The coefficients of variable *precipitation* are not significant as well as those of variable *temperature*, suggesting weather factors are not closely related to prairie spring wheat yields. As prairie spring wheat is one type of spring wheat and the growing seasons are similar, it is surprising that we did not find the significant climate impact on yields.

As the coefficients for all the soil zone dummy variables are not statistically significant, we can not find a yield difference between the soil zones. The coefficient of the year dummy variable 2000 and *2002* are negative and statistically significant, indicating the yields were lower in these years. For the variety dummy variables, estimated coefficients from both Tables are not statistically significant.

Overall, the results provide no support that the PBR Act has increased yields for prairie spring wheat.