Predicting Land Use Transitions on Land Neighboring Riding Mountain National Park

by

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Abstract

This study examines the influence of geophysical and economic factors on conversion of wetlands and grassland to cropland in the agricultural production region surrounding Riding Mountain National Park. An econometric land use share model is specified, using annual (2011-2021) parcel-level observations of crop share derived from the AAFC Cropland Inventory. Results suggest a positive correlation between crop revenue and cropland share, along with strong relationships between geophysical characteristics of the parcel and cropland share. Notably, income has a greater impact on cropland share on parcels with higher productivity soil. The parameters of the model are used to identify parcels that are at highest risk of conversion.

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Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

In this chapter, an overview of the research study is provided. The exploration includes an analysis of the influence of human activities on changes in land use, examining how these activities contribute to environmental degradation and the loss of habitats. The discussion covers trends and conservation initiatives related to these habitats. Additionally, the research problem, motivation, and specific research objectives are outlined.

1.1. Background

Land is an essential resource for the production of some commodities, such as agriculture, forest products, and dwellings, underscoring the profound human impact that land-use changes exert on the environment (Briassoulis, 2020; Bell et al., 2006). Alteration of land use is likely to exert the most significant human impact on the environment (Vitousek et al., 1997; Foley et al., 2005). In brief, land use "denotes the human employment of land" (Turner and Meyer, 1994). Land use change can involve shifting from one type of land use to another or modifying specific land use types, with variations in intensity or characteristics. Jones and Clark (1997) classified agricultural land use changes into intensification, extensification, marginalization, and abandonment. FAO (1995) also states that "land use concerns the function or purpose for which the land is used by the local human population and can be defined as the human activities that are directly related to land, making use of its resources or having an impact on them" (FAO, 1995). Its worth mentioning that the terms "land use" and "land cover" are distinct and not interchangeable. The literature emphasizes their differences to ensure accurate usage in studies related to changes in land use and land cover.[1]

Land cover refers to the physical and biological characteristics of the Earth's surface and its immediate subsurface (Turner et al., 1995). As it is defined by Meyer and Turner (1994), land cover is the physical, chemical, or biological classification of the terrestrial surface, such as grassland, forest, or concrete. In contrast, land use refers to the human activities associated with that cover, such as raising cattle, recreation, or urban living.

Private decisions about use of land can yield external benefits, such as the creation of recreational opportunities. On the other hand, land use can also result in notable external costs, such as non-point source pollution and alterations to wildlife habitats (Bell et al., 2006). Moreover, land-use change results in modifications to the spatial pattern of land use, including habitat fragmentation, which frequently leads to the deterioration of environmental quality (Plantinga and Lewis, 2014). Numerous species of great conservation concern exhibit sensitivity to the fragmentation of their habitats. This includes avian species (Askins, 2002; Faaborg, 2002), amphibians (Kolozsvary and Swihart, 1999; Lehtinen et al., 2003), and large mammals (Noss, 1994; Costa et al., 2005). The transformation in land use stands as the principal catalyst for the decline in biodiversity within terrestrial ecosystems and is anticipated to maintain this status in the foreseeable future (Millenium Ecosystem Assessment, 2005; Sala et al., 2000; Wilcove et al., 2000).

Human activities, likewise, particularly agricultural expansion and climate change have placed numerous grassland, wetland, and forestland ecosystems at significant risk (Lark et al., 2020; Rashford et al., 2011; White et al., 2000). Research conducted by Euliss et al. (2006) and Dahl and

[1] For example, Turner et al. 1995, 20; Meyer and Turner, 1994; Moser 1996.

Watmough (2007) reveal that over half of the wetlands in the North American Prairie Pothole Region (PPR) have suffered degradation or damage since European settlement. Challenges facing wetlands and waterfowl habitats are significant in Canada's western grain belt, where 95% of the land is suitable for farming (Trottier, 2002). Agriculture predominates the landscape, making it crucial to coordinate agri-environmental policies across provincial borders (Schmitz, 2008). Notably, from 1985 to 2001, over 500,000 acres of wetlands in Canada's Prairie Pothole Region (PPR) were lost, with 62% of these areas converted into cultivated crops (Watmough and Schmoll, 2007). Furthermore, as highlighted by Hoekstra et al. (2005), temperate grasslands, which have undergone extensive conversion for human use and get relatively less protection, are particularly susceptible to loss and deterioration.

The transformation of natural grasslands into cultivated farmlands has been a widespread practice in history and persists globally even today (Liu et al., 2005; Rounsevell et al., 2005; Stephens et al., 2008). Grasslands not only provide a benchmark for evaluating our past environment but also serve as a valuable source of food, medicine, recreational opportunities, genetic resources, and habitat for various species (Gauthier and Wiken, 2003). Furthermore, grassland loss reduces biodiversity (Foley et al., 2005; Green et al., 2005), releases carbon trapped in the soil (Foley et al., 2005), degrades water quality (Moss, 2008), and worsens soil erosion (Montgomery, 2007).

Likewise, wetlands have a unique and essential function in the regulation of the Earth's climate, preservation of the global hydrological cycle, preservation of ecosystem diversity, and safeguarding human well-being (Hu et al., 2017; Ramsar Convention Bureau, 2001). Wetland ecosystems offer both indirect benefits and direct economic value to humans (Costanza et al., 1997; Smardon, 2009). They possess the highest value per hectare among all types of ecosystems, with the total value of wetland ecosystem services accounting for 47% of the global ecosystem's value (Costanza et al., 1997). As a result, wetland ecosystems are recognized as crucial and highly productive ecosystems (Smardon, 2009; Mitsch et al., 2015).

Consequently, the protection of grasslands and wetlands has garnered significant attention, resulting in the proposal of numerous conservation initiatives and substantial investments (NFWF, 2016).

In areas primarily controlled by private landowners, there is a lack of motivation for these individuals to collaborate and make joint decisions that could impact the arrangement of land use and the resulting environmental effects. Land-use policies serve as a means to adjust private incentives, enabling the attainment of societal goals related to the spatial distribution of land uses (Lewis and Plantinga, 2007). Notably, a significant portion of habitats crucial for biodiversity conservation is situated on privately-owned land. A specific study revealed that 70% of species enlisted under the U.S. Endangered Species Act (ESA) rely extensively on non-federal land, primarily under private ownership, for the majority of their habitat (Natural Heritage Data Center Network, 1993). There are numerous public policies that impact private land conservation, including regulations at the local level such as zoning and land use ordinances, state and federal programs that compensate landowners for engaging in specific land use practices, such as the Conservation Reserve Program, as well as incentives that are integrated into tax codes. However, the primary ones involve acquiring fee simple interest in the land and establishing conservation easements, which are commonly used by non-profit conservation organizations (Parker and Thurman, 2018) and have become a crucial conservation method in North America (Parker and Thurman, 2013). Deciding which conservation method to use relies on how well it can preserve the values of the land while still respecting the goals of the landowner.

Since the introduction of the Manitoba Conservation Agreements Act in 1997, many conservation organizations, notably Manitoba Habitat Heritage Corporation (MHHC), Ducks Unlimited Canada (DUC), and Nature Conservancy Canada (NCC) have been acquiring conservation easements in Manitoba. The funding for most of these tools acquired in the prairie pothole region of Manitoba comes from the North American Waterfowl Management Plan (NAWMP). Launched in 1986, NAWMP aims to restore waterfowl populations, striving to return them to the levels observed in 1970 (Williams et al., 1999).

In the fee simple interest approach, the landholder relinquishes ownership of the land by transferring the title deed to a conservation agency. Through this process, the landowner surrenders all rights associated with the land, including the right to possess, occupy, use, and sell it, in exchange for a single payment. This transfer of ownership ensures the highest level of security for the conservation of the land. The fee simple approach is particularly appropriate for areas facing threats that necessitate outright land acquisition or when the land is vulnerable to multiple threats that cannot be addressed incrementally. Although effective in safeguarding select conservation areas, the initial expenses associated with acquiring land outright can be considerable compared to alternative conservation methods. Additionally, ongoing management costs may be elevated as the conservation organization acquiring the land either assumes direct management responsibilities or must arrange for third-party management services (Fishburn et al., 2009).

In contrast, under easement contracts, while land ownership remains with the initial landowners, they permanently transfer specific land use rights on the eased portion of the parcel to conservation agencies. Easement contracts are frequently utilized as a fair and consensual approach to precisely limit property rights and are thus commonly employed to protect habitats such as grasslands and wetlands (Mia et al., 2022).

The prairie pothole region of Manitoba sees a significant number of conservation easements and fee simple interests, primarily facilitated by two agencies: DUC and MHHC. MHHC, established in 1986 under the Manitoba Habitat Heritage Act, is a provincial Crown Corporation. On the other hand, DUC, a private non-profit organization, was founded in Canada in 1938. However, NCC, established in 1962, stands as Canada's primary national land conservation organization. Compared to MHHC and DUC, NCC has used more fee simple interest tool to protect habitats specifically in our study region (lands neighboring Riding Mountain National Area). Their efforts are concentrated on specific landscapes across the country recognized as vital for biodiversity conservation, often identified through comprehensive Conservation Blueprints and Ecoregional Assessments. They have successfully preserved over 2.8 million acres of ecologically significant land, spanning from coast to coast. In Manitoba alone, they have safeguarded and preserved more than 65,000 acres (26,305 hectares) spread across nine natural areas, including the Riding Mountain Natural Area (Hamel, 2015).

1.2. Research Problem and Motivation

Conservation agencies aim to preserve natural habitats on farmland by preventing its conversion. Agencies can obtain conversion rights from landowners through easements or by acquiring outright ownership of the land using the fee simple interest method. This approach ensures that the land remains in its natural habitat, safeguarding biodiversity, and ecological balance. Transferring all or a portion of land ownership rights to conservation agencies provides the greatest level of security. Often, the value of the land allocated for preservation is evaluated by a certified third-party appraiser. As the nature of either easement program and fee simple come with a bilateral agreement in which one party (conservation agency) is committed to paying a fee to the second party (landowner), issues related to a limitation of budget, regardless of whether the agency is private or public, are an obstacle to protecting all lands within an area. Targeting land at risk of conversion is essential because otherwise, both time and money will be wasted, resulting in a faster conversion process.

Because conservation organizations are constrained by limited annual budgets, it is in their interest to focus on a biologically important area they feel is at high risk of being converted (Costello and Polasky, 2004). Therefore, conservation organizations are concerned whether conservation easements or fee simple interests are just encumbering land that will never be put to another use (Lawley and Towe, 2014).

The key factor here is to investigate the possibility of transferring lands from various uses to agricultural use. To achieve this, we employ an econometric model that provides us with an overall understanding of land characteristics that lead to some lands being characterized with high or low risk of conversion. In this context, it is crucial to analyze the impact of biological land characteristics, particularly soil attributes, as well as economic factors such as expected income from farming. Emphasizing the significance of examining these factors, understanding the criteria influencing conversion allows us to predict which lands, with specific characteristics, are likely to be converted to annual cultivation in the future. This insight will aid conservation agencies in targeting their next conservation areas effectively.

1.2.1. Research Objectives

This study explores the influence of geophysical factors (soil capability class, elevation, slope, stoniness, erosion, and salinity) and weighted average income (as an economic factor) on land conversion to cropland (compared to water, wetland, shrubland and grassland, pasture, developed areas, and forest and mixed woods). Moreover, I provide projections of potentially vulnerable habitats for future conservation efforts by identifying characteristics and locations of lands at potential risk of conversion.

Many studies have explored the relationship between land use change and conservation programs from various perspectives. Specifically, research has examined the impact of conservation efforts, such as the implementation of conservation easements, on land values. These studies, however, often yield different results. This variability underscores the complexity of assessing the effects of conservation programs and highlights the need for context-specific analysis to understand how different conservation strategies influence land use and value. One set of research contends that conservation easements have negligible effects on the value of the restricted parcels (Nickerson and Lynch, 2001; Zang, 2004). Conversely, an alternative study asserts significant influences of conservation activities on both the restricted parcels and the neighboring land values (Irwin and Bockstael, 2001; Geoghegan, 2002; Farja and Rausser, 2007; Shultz and Taff, 2004; Lawley and Towe, 2014; Chamblee et al., 2011). On the contrary, certain studies, such as those conducted by Anderson and Weinhold (2007) and Lynch et al. (2007), fail to yield conclusive evidence regarding the impact of conservation activities on land values.

However, there needs to be a specific study that identifies lands at the highest risk of conversion and tracks conserved habitats based on land characteristics directly and investigate whether already conserved habitats are effectively targeted. Basically, past land use change studies use predictions to assess the impact of hypothetical or potential policy tools (Lewis and Plantinga, 2007; Radeloff et al., 2012; Lawler et al., 2014). In this study, I will use a land use share model to assess the impact of an actual policy by looking back on the past years performance of conservation programs in Manitoba.

To achieve the objectives of this research, I choose a land use share model that regresses the share of land in agricultural uses on land characteristics. I will undertake the following steps: first, I will estimate the parameters of a land use share model by regressing changes in the share of lands under crop use and their associated characteristics. Next, by using parameters from that model, I will characterize what types of habitats are at potential risk of conversion. Finally, I will rank parcels from higher to lower conversion risk. Extensive literature advocates for the preservation of habitats in peril of conversion (Ferraro and Pattanayak, 2006). This thesis examines the direct correlation between geophysical factors, economic indicator, and habitat loss in lands neighboring Riding Mountain National Park. Identifying at-risk habitats and establishing conservation priorities based on this integrated analysis remains an unexplored area in current research.

The findings indicate that an increase in weighted average crop revenue per acre leads to an increase in the share of land used as cropland. Additionally, there is a significant relationship between geophysical factors, such as soil capability, slope, elevation, salinity, and stoniness. Importantly, income exerts a more pronounced influence on cropland share in areas characterized by higher soil capability. This suggests that, as anticipated, lands with higher incomes derived from crop production contribute to habitat loss, indicating that farmers earning more income from their croplands are more inclined to convert habitats into cropland. Additionally, lands with higher soil capability, as expected, are more suitable for cultivating crops compared to those with medium and low capabilities. Also, the interaction effect reveals that income has a larger impact on the share of cropland in lands with higher soil capability compared to those with medium and low capability. This suggests that farming becomes more economically viable on better-quality lands, as higher soil capability enhances the benefits of increased income for agricultural use. This interaction effect indicates that the positive influence of income on cropland share is amplified in areas with higher soil quality.

According to model predictions, almost all municipalities in the study area have some parcels at high risk of conversion. When the predicted share of cropland is higher than the actual share, it indicates that those parcels have a potential probability of converting to cropland. This assessment is made on an annual basis. Although the mixture of fee simple interests and easement contracts are employed to protect habitats surrounding Riding Mountain National Park, the majority of habitat in this area require more attention based on the number of parcels at highest risk of conversion. Consequently, there is a need for further improvement by expanding coverage in these municipalities.

The organization of this thesis is as follows: Chapter 2 reviews previous studies that investigated the factors influencing land values. In Chapter 3, I introduce the econometric model utilized and provide its rationale. Chapter 4 presents the analysis results, followed by conclusions and recommendations in Chapter 5.

Chapter 2: Literature Review

This chapter delves into previous research investigating the effects of conservation activities and various policies on land use and land values. Conservation policies have garnered substantial attention and widespread use in North America, resulting in numerous empirical studies exploring these policies from various angles. This review will inform the selection of variables, research methodologies, and data requirements necessary for a comprehensive analysis. The first section examines policies and regulations related to land use and land values in North America. The second part discusses research on land use change models. The final section reviews literature about predicting changes in land use.

2.1. Policies and Regulations

When it comes to the policies and regulations affecting land use, the relationship between land conservation and public policies needs to consider. According to Parker and Thurman (2018), the concept of "private land conservation" pertains to the ability to generate amenities and services on privately-owned land, which can be enjoyed by the landowners themselves and those with whom they have agreements, as well as by the broader public. Conversely, public policy, ideally, should prioritize the management of benefits that do not exclusively accrue to landowners or their contractual partners. Consequently, public policy related to private conservation should appropriately focus on the regulation, financial support, and taxation measures that impact the provision of public goods from private land. Effective conservation efforts not only rely on the design of the programs themselves but also on the interplay of policies, preferences, and implementation strategies. This interrelation leads to the successful land conservation initiatives, highlighting the need for strategic decisions at various levels to maximize the impact of conservation programs.

There are numerous public policies that impact private land conservation, including regulations at the local level such as zoning and land use ordinances, state and federal programs that compensate landowners for engaging in specific land use practices, such as the Conservation Reserve Program, as well as incentives that are integrated into tax codes (Parker and Thurman, 2018).

In one of the studies about the influence of zoning on ecosystem services, Geneletti (2012) conducted case-study research in Chile's Araucanía region, aiming to empirically investigate the effects of different land-use zoning policies on the future provision of various ecosystem services, including water purification, soil conservation, habitat for species, carbon sequestration, and timber production. Geneletti's methodology involved creating land-use scenarios associated with different policies and assessing their impact on ecosystem service provision using spatial modeling tools. To facilitate comparisons between scenarios, he developed a set of metrics and elucidated trade-offs among ecosystem services through trade-off curves. Notably, Geneletti's findings underscored that, in this specific case study, the spatial configuration of land uses was just as influential as their acreage in determining the provision of ecosystem services. This emphasized the need to consider land-use patterns in scenario exercises aimed at supporting spatial planning.

Another study by Brown and Quinn (2018) examined the impact of zoning regulations on preserving natural resources, focusing on 65 watersheds in South Carolina, USA. Using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) framework, they assessed habitat preservation, carbon storage, and nutrient and sediment export as ecosystem services over a ten-year period. They found that increased development led to a decline in these services, with zoning mitigating the impact only on phosphorus export, highlighting the need for more explicit consideration of ecosystem services in zoning ordinances. The study emphasizes the importance of improved data and rigorous evaluation for informed governance decisions related to zoning and regional planning in urban watersheds, both in the public and private sectors.

In the broader context of global research on zoning policies and their environmental consequences, Geneletti's study in Chile underscores the importance of incorporating land-use patterns into spatial planning efforts to enhance ecosystem service preservation. Compared to Brown and Quinn's 2018 study, which examined the influence of zoning regulations on ecosystem services in South Carolina, these studies collectively emphasize the pivotal role of zoning policies in shaping outcomes related to ecosystem services and land-use planning.

As described by Stubbs (2014), the Conservation Reserve Program (CRP) stands as the largest federal private-land retirement program, offering financial incentives to landowners for voluntarily taking agricultural land out of production for extended periods, typically ranging from 10 to 15 years. This withdrawal from agricultural use aims to enhance soil and water quality and foster wildlife habitat. The CRP was originally authorized under the Food Security Act of 1985, initially serving as both a tool for managing agricultural supply by reducing land in production, potentially influencing commodity prices, and as a means to deliver environmental benefits. Building on the discussion of the Conservation Reserve Program (CRP) and its role in land-use management for environmental benefits, it is essential to explore the subsequent study examining the impact of CRP participation on land values. In their 2010 study, Wu and Lin evaluated the impact of the Conservation Reserve Program (CRP) on land values. Their analysis indicated that CRP participation had the most substantial effects in the Mountain, Southern Plains, and Northern Plains regions, increasing average farmland values by 5% to 14%, 4% to 6%, and 2% to 5%, respectively. Additionally, the CRP had a statistically significant impact on developed land values, albeit with smaller percentage increases. The CRP's impact on developed land values is due to its role in slowing down land development, which reduces the expected increase in land value and the potential for future development (in this study, developed lands refer to areas used for infrastructure or housing rather than agriculture). These findings highlight the regional variability in CRP's influence on land values and offer insights into the program's economic implications for land-use management.

Expanding on the examination of CRP, the study by Babcock et al. (1997) explores the direct attainment of environmental advantages, such as enhanced surface water quality, decreased water and soil erosion, and better wildlife habitats, accommodating variations in agricultural productivity and environmental gains. They examine three targeting approaches: maximizing environmental benefits, minimizing acquisition expenses, and maximizing net benefits. Their analysis reveals that the efficiency drawbacks resulting from cost minimization and benefit maximization hinge on the diversity in farmland productivity and environmental advantages, as well as the correlation between them. For instance, wind erosion and CRP rental rates display a negative correlation, indicating that targeting low-cost lands can effectively reduce wind erosion. Wildlife habitat, also, is evenly spread across CRP land, leading to minimal efficiency loss with any of the three targeting strategies under consideration.

Apart from that, property taxes play a significant role in shaping the management of privately-owned forest and agricultural lands (Hibbard et al., 2003). Recognizing this pivotal role, it is imperative to explore into taxation policies and their impact on land use and land values. Tax measures, wield considerable power in shaping decisions related to land management.

Polyakov and Zhang (2008) analyzed the impact of property taxes on transitions between agricultural, forestry, Conservation Reserve Program, and developed land uses in Louisiana. They employed a random parameters logit model using data from the National Resources Inventory plot dataset to estimate land-use conversions. The results of their research indicate that changes in land use exhibit limited sensitivity to fluctuations in property taxes. Furthermore, through simulation, it is observed that the current use valuation policy, while effective in slowing down the development of rural lands, also influences transitions between various forms of rural land use. As taxation policies have multifaceted influence on land use and land values, it is essential to consider innovative approaches that address conservation challenges in human-dominated landscapes.

For an extended period, governments have undertaken measures to safeguard land from development, employing methods such as direct acquisition and land use regulations. However, in recent times, a shift towards more decentralized and incentive-driven approaches has gained prevalence on a global scale (Salzman, 2005; Jack et al., 2009; Alix-Garcia et al., 2016). In this regard, one policy activity that has recently received significant attention is conservation easements, which has gained significant attention among non-profit conservation organizations.

One such approach, as highlighted by Schuster et al. (2018), focuses on the intricate relationship between taxation policies and biodiversity conservation (like conservation easement) on private lands. In their study, taxation policies and biodiversity conservation on privately owned lands, with a focus on addressing challenges in preserving imperiled ecosystems like coastal Douglas fir forests in Canada, primarily due to the high costs associated with land acquisition was examined. Their approach involves prioritizing parcels based on biodiversity value. By eliminating property taxes on high-priority parcels and applying modest tax increases to lower-priority ones, their research reveals a potential pathway for efficiently achieving conservation goals using conservation easements. In this regard, landowners of high-quality parcels who participate in conservation programs will be exempt from property taxes, as the funding for conservation projects will be provided by a moderate increase in property taxes on lower-quality parcels.

The exploration continues the intricate relationship between land conservation and public policies, where the focal point is conservation easements. These agreements, which might be beneficial for preserving our valuable habitats, have significantly influenced land values, leaving a lasting impact. The context of rising agricultural land values in North America's Prairie Pothole Region (PPR), intertwines with the environmental challenges posed by cropping methods contributing to climate change, as discussed by Muhammad et al. (2018) and Zhang et al. (2021). Amidst these factors, the grassland easement payment rate in this region is anticipated to rise, underscoring the ongoing transformation in land conservation practices in response to environmental and economic dynamics. One of the studies that discuss rising in agricultural land values is done by Deaton and Lawley (2022). This study offers a comprehensive review of agricultural economics literature on farmland prices, focusing on the capitalization model as a framework. The research highlights five key areas influencing farmland prices: boom-bust cycles, the impact of government subsidies, agricultural zoning, climate change, and restrictions on non-local buyers. The study emphasizes the need for improved econometric methods and structural models to better predict farmland prices, particularly short-term fluctuations. Additionally, it suggests that future research, especially in Canada, could benefit from cross-border studies to understand regional differences and policy impacts.

Despite the significance of easement conservation policy, questions about its effectiveness have persisted. Addressing this, Braza (2017) developed a spatial econometric approach, applying propensity-score matching to estimate the effect of a grassland conservation easement program initiated by the U.S. federal government. Braza's methodology involved predicting tract enrollment in the easement program using factors like agricultural suitability, habitat quality, and spatial interactions among neighboring tracts. By comparing enrolled tracts with similar unenrolled counterparts, he discerned that approximately 16.9% of the protected land would have been cultivated without the program, indicating a significant reduction in habitat loss. However, his findings also emphasized the need for careful consideration in enrolling tracts with low cropland suitability, suggesting a nuanced approach to maximize the effectiveness of conservation easements in agricultural regions. This study not only underscored the tangible impact of conservation easements in curbing habitat loss but also highlighted the importance of sophisticated modeling techniques in understanding the nuanced dynamics of conservation efforts. Delving deeper into the realm of conservation strategies, Reichelderfer and Boggess (1998) shed light on the intricacies of the Conservation Reserve Program (CRP). Their study revealed that the program's effectiveness, as perceived by its administrators, was profoundly influenced by the selection criteria and decisions made during implementation, particularly in the inaugural year. Notably, their simulations indicate that manipulating key control variables in future implementation strategies could substantially enhance the program's performance. Relating this back to our prior discussions, including the studies on conservation easements and the impact of taxation policies, Reichelderfer and Boggess' research emphasizes the importance of well-informed policy decisions in achieving conservation goals.

The recent studies by Miao et al. (2022, 2022b) significantly contribute to the evolving landscape of conservation easements and their impact on land values. They introduced an analytical framework that delves into the complexities of grassland easement acquisition, providing insights for both agencies and landowners. One of their key findings challenges conventional wisdom: a higher conversion probability does not always equate to a higher easement value. This revelation underscores the nuanced dynamics at play in the valuation of grassland easements, shedding light on the intricate factors that influence their economic worth.

Expanding on this approach, Miao et al. (2022b) delved deeper into the environmental aspects of grassland conversion. Their focus on environmental benefit additionality and the geographical spillover impact of grassland conversion adds a layer of complexity to the evaluation process. Through numerical analysis, they highlighted the effectiveness of heuristic methods, offering practical strategies to enhance environmental benefits in the context of easement acquisition. These findings enhance our comprehension of the relationships among conservation, environmental impact, and economic valuation, offering practical insights for agencies advising landowners.

Together, these studies augment the existing body of knowledge on conservation easements, emphasizing the importance of considering diverse factors such as conversion probability, environmental benefit additionality, and geographical spillover impact. This comprehensive approach is essential for informed decision-making in conservation initiatives, bridging the gap between economic considerations and environmental sustainability.

Apart from the easement program and its popularity and effectiveness compared to other policies such as taxation or zoning, fee simple interests need to be considered. Fee simple, like easement, is related to the ownership of lands. However, through the acquisition of fee simple by conservation agencies, they will have full ownership of the land, which decreases tracking and enforcement costs (these costs typically include legal fees, and administrative expenses), and the conservation agency undertakes the responsibility to manage and sustain the property (unlike easement, where full ownership still belongs to the landlord). In this regard, Parker (2004) suggests an economic model to describe whether conservation agencies will be better of by choosing conservation easements, or fee simple acquisition. The article discusses how conservation agencies undertake the preservation of environmental amenities on private lands through either fee simple or conservation easements. Despite the potential for higher transaction costs associated with conservation easements due to the necessity of detailed specifications and enforcement, they offer the advantage of promoting more cost-effective production of goods such as crops and beef by capitalizing on landowner specialization. Analysis using data from the Land Trust Alliance reveals that agencies tend to prefer easements when transaction costs are minimal and gains from landowner specialization are significant, often opting to conserve scenic views over agricultural land through easements and enhance ecological functions on non-agricultural land through fee simple. Furthermore, the article explores the impact of tax incentives on the prevalence of conservation easements, acknowledging their role in the trend. However, despite the benefits of easements, the inherent imperfect division of land interests can result in expensive monitoring and enforcement, thereby diminishing the cost savings derived from specialization.

2.2. Conservation Easement and Fee Simple: Land-Use and Land Values

Land-use regulations can impact property values in complex ways, often misunderstood by many. These regulations can have positive effects on property values through two main mechanisms. Firstly, the "amenity effect" arises when regulations protect or enhance amenities and services, such as environmental protections or controlling noise, making an area more attractive and raising property values. Secondly, the "scarcity effect" occurs when regulations limit land availability for specific uses, increasing demand for available land and driving up prices. These effects are often misinterpreted, especially when individual exemptions are granted, leading to misconceptions about the regulations' impact on property values. This nuanced understanding is crucial for evaluating the true influence of land-use regulations on property markets (Jaeger, 2015).

Expanding on this knowledge, Langpap (2004) investigates the effectiveness of incentive programs as complementary measures to the Endangered Species Act's land-use restrictions. Analyzing data from a survey of private forest owners, the study discerns that targeting incentives toward younger landowners who recently acquired property, own substantial woodland, and have conservation interests may significantly boost participation rates in these programs. This strategic targeting underscores the importance of understanding landowner demographics and interests in the implementation of incentives.

In a different realm, Atwood et al. (2007) delve into urban outdoor water conservation programs. Their study in Guelph, Ontario, assesses residents' perceptions and satisfaction with such initiatives. Despite broad support, residents exhibit uncertainty regarding the effectiveness of these programs and their enforcement. Factors such as neighborhood, gender, and environmental attitudes significantly shape residents' assessments. The study underscores the importance of clear communication and effective program enforcement, highlighting the need for tailored approaches based on residents' attitudes and neighborhood contexts.

Shifting focus to Alberta, Canada, Hailu et al. (2000) employ a multi-program contingent valuation (CVM) design to assess the value of three ecosystem conservation programs including Old Growth Forests, Prairie Grasslands, and Mountain Stream Ecosystems. Their unique approach incorporates direct reminders of substitute/complementary programs and budget constraints. Contrary to previous findings, two environmental programs appear complementary, suggesting a more complex relationship between conservation initiatives. This study enhances our understanding of how different conservation programs interact. It provides insights into the relationships between conservation policies, property values, and resident attitudes. By considering landowner demographics, resident perceptions, and program interactions, policymakers can implement more effective and nuanced conservation initiatives.

In the context of affecting land-use regulations on property values, Jaeger (2006) delves into the intricate nuances of land-use regulations, particularly exemplified in laws like Oregon's Measure

37. Measure 37 stipulates that if a land-use regulation decreases the property's market value, the government must either compensate the landowner for the loss or grant an exemption from the regulation. The confusion arises from the intermingling of two distinct economic concepts: the impact of a land use regulation on property values across multiple parcels and the effect of removing a regulation from a single property. Land-use regulations can exert positive (amenity and scarcity effects) as well as negative influences on property values. However, interpreting a positive value for removing a regulation as evidence of a negative impact on property values is misguided. Despite this, positive estimates for individual exemptions are frequently misunderstood as grounds for compensation, perpetuating the misconception that land-use regulations inherently devalue properties. Clarifying these distinctions is pivotal for precise evaluations of the economic effects of land-use regulations on property values, especially in governmental responses to claims under Measure 37.

This complexity in interpreting the economic consequences of land-use regulations serves as a backdrop for studies like Lawley and Towe's (2014) investigation into perpetual habitat protection easements. Lawley and Towe (2014) employed matching and regression adjustment techniques to examine the land value discount resulting from these perpetual habitat protection easements. Their research revealed a significant decrease in land prices, with the typical eased parcel experiencing a reduction of about $86 per acre for each acre of protected habitat.

In their examination of Canadian landscapes, Brown et al. (2011) assessed landowners' willingness to adopt conservation easements through a uniform price auction with a hidden reserve price. This approach enabled greater landowner engagement by offering a transparent and equitable process, which increased confidence among landowners that they would receive fair compensation. Their study provided valuable insights for the successful implementation of a long-term easement acquisition program, emphasizing both the practical aspects of conservation implementation and the importance of engaging landowners

Shifting focus to the American Midwest, Farmer et al. (2015) conducted a comprehensive survey among landowners to decipher the factors influencing the establishment of conservation easements between 2000 and 2010. Their findings illuminated the pivotal role of financial incentives, particularly for landowners receiving monetary benefits. Interestingly, absentee landowners appeared less swayed by financial motivations, suggesting the nuanced interplay of personal and economic factors in decision-making processes. This study enriches the understanding of the diverse motivations guiding landowners' choices in different contexts.

Adding depth to the exploration, Lawley (2014) examined shifts in agricultural land value discounts resulting from prairie pothole habitat in Manitoba. Analyzing agricultural land transaction data spanning almost two decades, Lawley's research revealed a significant increase in the discount applied to wetland areas. This unexpected trend points to evolving perceptions and economic considerations related to wetland conservation, highlighting the dynamic nature of land valuation processes over time.

Chamblee et al. (2011) investigate the impact of acquiring land parcels through fee simple or easements on the value of the affected and surrounding land. They analyze land sale data from Buncombe County, North Carolina, spanning 1996 to 2008. Their analysis includes various parcel attributes, location factors, and watershed characteristics of the sold parcels. To account for spillover effects from fee simple or conservation easements, the authors employ several methods. Initially, they consider the distance between the sold land and the nearest conserved parcel, irrespective of the type of conservation or its timing. They then create a binary easement variable indicating whether the nearest conserved parcel has an easement or is conserved in fee simple.

Additionally, they construct an interaction term between distance and easement status to capture price effects of conservation easements relative to fee simple arrangements. Moreover, they interact these variables with a post-conservation indicator to differentiate between pre-conservation and post-conservation effects. Utilizing a spatially lagged hedonic model, they find that post-conservation, both easements and fee simple ownership significantly increase the value of surrounding land. They observe premiums from conservation activities, with the highest premium of 46% when the conserved and sold parcels are adjacent. However, this premium diminishes with increasing distance from the conserved parcel.

2.3. Land-Use Share Models

Empirical models analyzing land use and its changes are vital for evaluating land use theories and shaping policies concerning land-use transitions. These models serve to uncover the reasons behind specific land use patterns and the factors motivating changes in land use over time. For instance, they can assess how the economic profitability of different land uses and the inherent physical attributes of land, such as its quality, impact decisions regarding land use (Bell et al., 2006).

The aim of developing land-use share models is to measure the connection between the proportions of land designated for various purposes and the presumed factors influencing land use, such as the economic gains from a specific use. These estimation outcomes reveal the significant factors shaping individual choices regarding land use. Additionally, these results can be utilized to predict alterations in land use patterns when the underlying determinants of land use undergo changes (Bell et al., 2006). As we delve into the domain of land-use share models, we encounter insightful research that expands our comprehension of optimal land allocation strategies. One such study by Plantinga et al. (1999) delves into the cost-effectiveness of afforestation, a method recognized by the Kyoto Protocol and the U.S. Climate Change Plan for reducing atmospheric CO2 concentrations. Using econometric land use models, the researchers estimated marginal costs of carbon sequestration in Maine, South Carolina, and Wisconsin. Employing standard logistic share equations, the study derived optimal land allocation rules from individual land managers' profit-maximization considerations. Particularly, the study focused on landowners' decisions regarding forest and agricultural land allocation, incorporating an optimal dynamic allocation rule due to differing periodic returns from these lands. Noteworthy findings that emerged: previous studies tended to underestimate carbon sequestration costs in afforestation programs, affirming afforestation as a relatively low-cost method for reducing CO2 concentrations. Additionally, Wisconsin offered the most economically viable opportunities for carbon sequestration, while in South Carolina, projected population changes significantly influenced costs. This study significantly contributes to our understanding of land-use models by providing nuanced insights into the intricate dynamics of carbon sequestration strategies.

In another study, Rashford et al. (2011) creates a land-use model to estimate the share of land in eight agricultural uses in some of the Canadian western provinces such as: Alberta, Manitoba, and Saskatchewan. Their model was then used to anticipate future land use in order to better understand the possible effects of agricultural land-use change on wetland and waterfowl habitat. Their findings suggest that agricultural growth and escalation are expected to continue, with an increase of more than 10 million acres of intensive spring crops projected. The anticipated transformation of pastureland (which harbors the most productive wetlands and waterfowl habitat), varies throughout Canada's pothole area, indicating the potential effectiveness of targeted conservation efforts.

2.4. Land-Use Changes and Future Predictions

Anticipating future changes in land use holds significant value in assessing the status of protected areas, enabling the identification of potential challenges and conservation possibilities. Researchers (Pressey et al., 2007; Fleishman et al., 2011; Davis and Hansen, 2011) have emphasized the importance of such projections. For instance, the encroachment of urban and agricultural developments near protected regions could heighten threats. Conversely, scenarios where land use intensity decreases present opportunities for natural habitats to expand and enhance connectivity around these protected areas (Fischer et al., 2006; Hansen and DeFries, 2007; DeFries et al., 2007).

Martinuzzi et al. (2015) assess potential land use changes surrounding different types of protected areas in the United States under various socioeconomic scenarios. They examine econometric-based forecasts of future land use change in 1260 protected areas, including National Forests, Parks, Refuges, and Wilderness Areas, from 2001 to 2051, under various land use strategies and agricultural prices. According to their findings, urban growth near protected areas will remain a serious concern and will increase by 67% under business-as-usual conditions. Discouragement of development, for example, through zoning, can lessen future urban pressures around National Forests and Refuges in the East, but the implementation of an afforestation programme can enhance the quantity of natural vegetation around some Refuges across the United States.

The study conducted by Sohl et al. (2016) aimed to compare projections from various land-use and land-cover (LULC) models in the United States. These models offered different scenarios for future land use, but the analysis revealed significant inconsistencies among them. Even when assessing the same scenarios, projections differed substantially between models. Agricultural trend forecasts, in particular, were often unrealistically high. The study pointed out discrepancies in categorical definitions among models and recommended standardizing historical data sources. To address uncertainties, ensemble modeling approaches were suggested. Overall, the study highlighted the need for improved theoretical foundations and modeling techniques in LULC studies due to the profound effects of land-use changes on ecological and societal processes.

In the study by Zhang et al. (2022), researchers analyzed future land use and cover changes in the middle reaches of the Yangtze River basin (MYRB) under different scenarios (SSP1–26, SSP2–45, SSP5–85). Historical and future LULC data were obtained using advanced modeling techniques. The study found accurate simulations of LULC changes, including forest expansion and farmland reduction, influenced by factors like GDP, population, temperature, and precipitation. These findings provide essential insights into the mechanisms of LULC changes in the MYRB, aiding ecological and climatic studies.

2.5. Conclusion

To conclude, this exhaustive literature review provides a deep understanding of the multifaceted landscape of land use and conservation policies. It illuminates the pivotal role of diverse regulations, from zoning ordinances to taxation measures, in shaping land values and guiding conservation efforts. Conservation easements, influenced by complex factors such as financial incentives and evolving environmental considerations, emerge as crucial tools in the preservation of imperiled ecosystems. The intricate evaluations of their impact on land values highlight the need for nuanced assessment methods. Furthermore, land-use share models offer valuable insights, elucidating the factors influencing individual land use decisions and providing guidance for effective policy formulation. Looking ahead, the challenge lies in predicting future land use changes with precision, necessitating advanced modeling techniques driven by economic indicators, population dynamics, and environmental factors. In the face of escalating environmental pressures, this review underscores the importance of a holistic understanding of land use dynamics. By comprehending the interconnections between policies, conservation initiatives, and advanced modeling approaches, policymakers and researchers can navigate the intricate landscape of contemporary land management. This comprehension is vital for fostering sustainability and biodiversity conservation amidst the relentless march of urbanization and agricultural expansion.

Chapter 3: Methodology

This section presents details about the methodology used in this research. Specifically, it covers the study area, the data utilized along with its sources, and the selection of the empirical model and its corresponding structure.

3.1. Study area and data sources

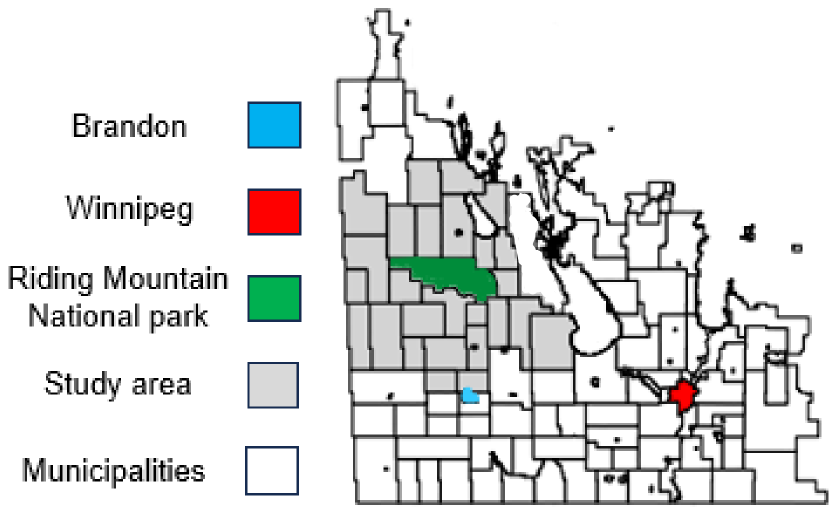

Figure 1. Study Area

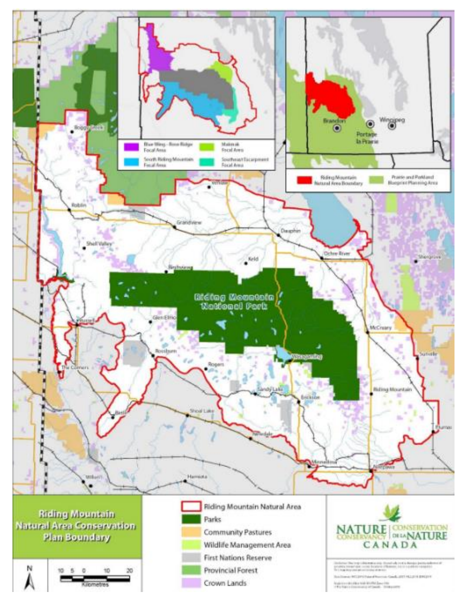

Figure 2. Riding Mountain National Area Conservation Plan Boundary (Neufeld and Hamel, 2018)

This study will be conducted in the southwestern part of the prairie province of Manitoba, focussing on an area referred to as the Riding Mountain Natural Area by NCC (see figures 1 and 2). I chose this study area for several reasons. First, it stands as one of the most expansive and ecologically functional natural regions in southwestern Manitoba. Second, it has gained support from local communities, who have advocated for the preservation and improvement of its prairies, forests, wetlands, and riparian areas. This effort aims to create a diverse and connected landscape that can withstand the challenges posed by climate change (Neufeld and Hamel, 2018). Moreover, the region benefits from a blend of recreational activities, ecotourism ventures, resource extraction industries, and agricultural practices. The agricultural significance of the area is attributed to its fertile farmland, which in some cases is suitable for conversion to cropland. Consequently, NCC is involved in conservation efforts within the region. These activities not only contribute to the area's ecological sustainability but also enhance its natural beauty. Moreover, since this study primarily delves into areas and lands profoundly impacted by the fee simple (and some part of it by easement) program, and taking into account data availability, which will be discussed in greater detail later on, the study's scope is limited to the municipalities and environs surrounding Riding Mountain National Park (RMNP), which is a part of Prairie Pothole Region (PPR), as illustrated in figure 1.

The PPR offers a home to diverse flora and fauna and acts as a vital nesting and breeding ground for migratory birds. Moreover, it fulfills hydrological, biochemical, and social functions such as floodwater management, water purification, carbon cycling, and providing aesthetic and recreational value (Euliss et al., 2006; Dahl and Watmough, 2007; Gleason et al., 2009). RMNP in west-central Manitoba is an extension of the Boreal Forest Region, covering 3,000 square kilometers (Rowe, 1972). Bordered by the Aspen Oak and Aspen Regions (Rowe, 1972), RMNP's diverse landscape includes rolling hills, meadows, lakes, and wetlands. The park houses endangered species and hosts a rich variety of habitats, including fescue prairie—one of the rarest prairie types in the province (Manitoba Provincial Grass Campaign Committee, 2008)—and mixed-grass prairie. Designated as a UNESCO Biosphere Reserve, RMNP is important for conservation, boasting woodlands and wetlands identified as top priorities for protection (MacDonald et al., 2017).

3.2. Empirical Model

Empirical models examining land use and its changes play a pivotal role in validating land use theories and shaping policies geared towards land management. These models are instrumental in pinpointing the reasons behind specific land use patterns and understanding the forces steering changes in land use. They enable researchers to analyze factors such as the economic returns of different land uses and the physical attributes of land (such as land quality) that influence decisions related to land use (Bell et al., 2006).

This study employs a land use share model to assess the effectiveness of conservation easement and fee simple program on mitigating habitat loss. The selection of this empirical model is driven by its widespread use in existing literature (Lichtenberg, 1989; Parks and Murray, 1994; Parks and Kramer, 1995; Wu and Segerson, 1995; Hardie and Parks, 1997; Plantinga et al., 1999; Ahn et al., 2000; Plantinga and Wu, 2002) and its appropriateness in addressing the research query.

Models focusing on parcel data in the context of land use encompass explanations of land use, land values, and land-use conversion. All these models share a common foundation: the premise that land is diverse, consisting of various characteristics within a parcel. These models operate on the idea that land use, value, or changes can be predicted based on the specific characteristics inherent to each parcel (Bell et al., 2006). However, it's crucial to exercise caution, as there are distinctions in how empirical models behave within each of these three categories.

Models addressing land use typically assume that land is allocated among various productive uses, such as agriculture, forestry, or development. The assumption here is that these resources will be utilized if it proves to be profitable. The decision regarding a specific land use is determined by comparing the net present value, considering the profitability, across all potential land use options (Nelson and Hellerstein, 1997). Nevertheless, economic models of land-use conversion resemble land use models, differing in their explicit focus on explaining shifts in land use over time, instead of merely allocating land to different uses at a specific moment (Bell et al., 2006). The assumption here is that every landowner allocates a uniform land parcel to the use that yields the highest present discounted value of net returns, after subtracting conversion costs. According to earlier theoretical findings (Stavins and Jaffe, 1990; Plantinga, 1996), this allocation method is deemed optimal when landowners maintain fixed expectations regarding conversion costs and future net returns (Lewis and Plantinga, 2007).

One approach that has been widely used in estimating the land use and land-use conversion is land-use share model (Lichtenberg, 1989; Parks and Murray, 1994; Parks and Kramer, 1995; Wu and Segerson, 1995; Hardie and Parks, 1997; Plantinga et al., 1999; Ahn et al., 2000; Plantinga and Wu, 2002). Estimating land-use share models serves the purpose of measuring the connection between the proportions of land assigned to different uses and the presumed factors influencing land use, such as the net return associated with a specific use. The outcomes of these estimations reveal the crucial determinants that influence individual choices regarding land use. Moreover, these results can be employed to predict how land use might alter if the factors influencing land use were to change. Previous land use change studies use predictions to assess the impact of hypothetical or potential policy tools (Lewis and Plantinga, 2007; Radeloff et al., 2012; Lawler et al., 2014). In this study, I will use a land use share model to assess the extent to which an actual policy is securing habitat in regions that are at high risk of conversion.

I will use a land-use share model to estimate risk of habitat loss. This model lets me assess changes in the share of a parcel in cropland, C_{pt}, over time and across parcels. In this study, a parcel refers to a quarter section of land delineated by the Dominion Land Survey in western Canada, specifically in Manitoba. These parcels are organized into square mile sections, further divided into four quarter sections (each constituting a 160-acre square plot in average. However, there are some parcels with larger or smaller size as well). The legal description ID assigned to each quarter section identifies its geographical location within Manitoba (Lawley and Yang, 2015). It's worth mentioning that all the parcels considered for this study are owned by private organizations or private landowners. The key point in considering these parcels is to understand the impact of landowners' decisions on land-use changes, which are affected by the income variable. This will be explained in more detail in the following sections.

The general form of the model is as follows:

$$(1) \qquad C_{pt} = \alpha + X_p'\beta + \lambda Z_{rt} + \gamma_m + \delta_t + \varphi LCC_p * Z_{rt} + \xi_{pt}$$

where α, β, λ, γ_m, δ_t, φ are parameters to be estimated and ξ is the error term. The p indexes the individual parcel and the t indexes year. The dependent variable (C_{pt}) is the cropland share measured as the acres of the parcel in annual crops divided by the total area of the parcel, for each parcel and in each year. The explanatory variables are classified as follows. The X_p' is a vector of the parcels' physical characteristics, including the agricultural capability of the soil (LCC_p) or some other soil characteristics such as salinity, stoniness, erosion, slope, etc. Z_{rt} captures a Census Agricultural Region (CAR) weighted average per acre crop revenue. The model also includes vector of municipality fixed effects (γ_m), and a year-fixed effects, (δ_t), which are estimated variables that account for unobserved time-invariant parcel/municipality characteristics and year-specific factors that affect land uses in the study region, including the interest rates, exchange rates, and inflation.

3.3. Empirical Model Structure

This section discusses the variables used in the model. Moreover, this section will provide a brief overview of the techniques that previous authors have used to address potential econometric problems and will highlight the procedures that will be employed in this study to overcome these issues.

Incorporating the interaction term $LCC_p * Z_{rt}$ in the model, as inspired by the works of Lewis and Plantinga (2009) and Plantinga et al. (2007) accounts for the specific ways in which soil capability classes (LCC_p) influence the weighted average income at the agricultural region level (Z_{rt}). This interaction term allows us to capture how variations in soil capability interact with income to impact land use shares, providing a more detailed understanding of the relationship between agricultural potential and economic outcomes within municipalities. This interaction term is essential because it links agricultural productivity, represented by soil capability classes, with economic outcomes, denoted by weighted average income. The significance of this interaction term lies in its ability to capture deviations in land use shares from the municipality average due to variations in soil capability. By including this term, the model allows the net revenue or economic outcomes for parcels to deviate based on observable land quality differences. This means that the interaction between income and soil capability helps to explain how higher soil capability can enhance the economic benefits of agricultural use, leading to change the share of cropland. This is important because it allows for a more precise analysis of how agricultural potential, as influenced by soil limitations, impacts overall economic performance within a municipality. This approach not only aligns with existing literature but also enhances the robustness of the model, ensuring that it considers both economic and agricultural factors in tandem.

As discussed earlier, in this study, the dependent variable was measured by calculating shares, representing the proportion of cropland concerning other land uses. This methodology was also adopted to capture the nuanced variations in independent variables, specifically, soil characteristics such as erosion, salinity, and soil capability class. Each variable was expressed as a share, reflecting its contribution within the overall parcel composition.

In the context of this approach, to avoid the dummy variable trap and multicollinearity, one category within each set of categorical variables (such as levels of erosion, salinity, or soil capability class) is omitted from the regression model. In my regression model, I omit the following categories to avoid linear dependence: parcels with low capability, high salinity, high stoniness, and high erosion. The remaining categories are interpreted relative to these omitted reference categories.

Moreover, I utilize municipality and time fixed effects. The municipality fixed effects account for consistent spatial variations that are unique to each municipality, encompassing factors like varying investments in local infrastructures such as roadways and bridges, as well as municipality-specific taxation rates. Meanwhile, the year fixed effects address time-specific factors that impact land prices within the research area, ensuring a comprehensive control for both spatial and temporal variations.

3.4. Variable Choice and Data Description

Econometric land-use studies may be divided into two categories by the sort of data used and in terms of approach: aggregated data vs parcel level data. The benefits of parcel level data are that the unit of observation corresponds to the scale at which the underlying spatial process occurs, which minimises data measurement issues, and the scale of the data correlates to the economic decision of interest. Despite these benefits, creating and estimating spatial micro-level models for big datasets presents obvious numerical problems, such as massive datasets which require data management and computer resources, and modeling difficulties (Bell and Irwin, 2002). I will use parcel level data from 2011 to 2021 in parcels neighboring RMNP to fulfill this study.

The literature and data availability determine which variables to include as dependent and explanatory variables. I make use of the extensive data set at my disposal and can control for several explanatory factors, such as physical parcel characteristics, soil capability class, and the weighted average revenue at the municipality level.

Dependent variable (share of lands in cropland) – I use the percentage of crop use in each parcel per year compared to other land usages including water, shrubland and grassland, urban/ developed/greenhouse areas, pasture, wetland, and forest and mixed wood.

Independent Variables – The choice of the independent variables is based on the need for the study and the related literature. Literature suggests some physical parcel characteristics such as the size of the parcel (Nickerson and Lynch, 2001; Zhang, 2004; Shultz and Taff, 2004; Farja and Rausser, 2007), slope of the parcel (Chamblee et al., 2011; Lawley and Towe, 2014), elevation of the parcel (Chamblee et al., 2011; Lawley and Towe, 2014), and soil capability class (Lawley and Towe, 2014). I therefore incorporate these variables in my regression. I also added erosion, stoniness and salinity based on the data availability and to the completion of the lands' physical characteristics (as these are the characteristics that used by MLI to measure the soil capability). Further, I include crop revenue as it has also been found to have an impact on land use and as an economic term suggested by Lawley (2018) and Lewis and Plantinga (2007).

3.4.1. Data Description

In this section, I elaborate on the variables utilized in this study. I furnish details about the data source for each variable and explain their construction when applicable.

I have generated all the land characteristic variables at the parcel level. However, for this study, I have restricted the analysis to parcels comprising 40 acres or more. This choice is motivated by the need to ensure more reliable data, given the potential errors inherent in parcels. Such errors may include the presence of temporary puddles due to seasonal rainfall, leading to underestimations of land uses such as cropland. However, small parcels are typically excluded because they are more likely to be used for residential or recreational purposes rather than agricultural use. In contrast, larger parcels are expected to provide closer approximations to real land uses and yield more reliable estimates (the discussion related to the misclassification error will be further explored in subsequent chapters). Moreover, within the comprehensive dataset at my disposal, certain parcels were overlooked in specific years due to issues related to data quality or omission in measuring certain areas. To enhance the uniformity of the dataset, I have opted to retain only those parcels for which complete data is accessible across all the years.

As it mentioned earlier, my dependent variable is a share of cropland. Share of land in different uses is available at AAFC in TIF format as a raster shape file.[2] So, it is already converted into a

[2] https://open.canada.ca/data/en/dataset/ba2645d5-4458-414d-b196-6303ac06c1c9

polygon shape file using ArcGIS. Given that my dependent variable pertains to land under crops, it is pertinent to specify the exact category of land that qualifies as cropland. With reference to the Canadian Crop Inventory definition, agricultural land is including annual and perennial crops, and would exclude grassland. However, each type of crops (such as barley, oat, rye, etc.) is defined as a separate class with its own code and label and are aggregated together to consider agricultural area.[3] However, as per the Manitoba Land Initiative, Agricultural cropland is specifically characterized as lands dedicated to the production of annual cereal, seed, and specialty crops. These lands are typically cultivated on an annual basis, emphasizing their primary use in the

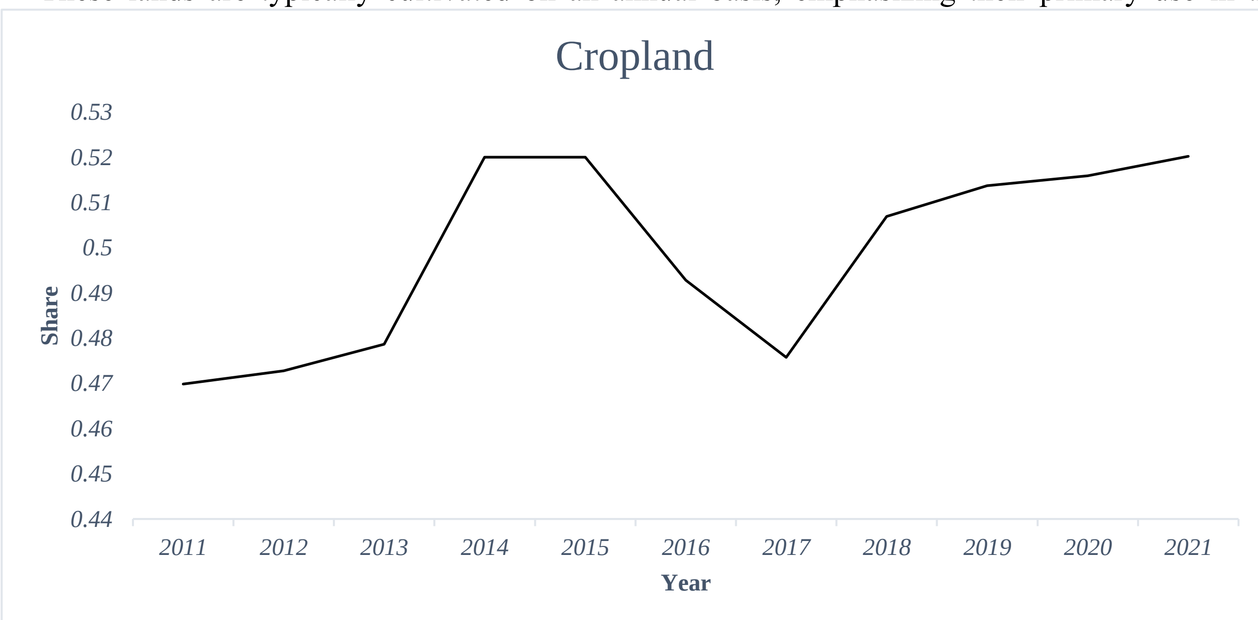

Figure 3. Average Share of Cropland in Parcels Neighbouring Riding Mountain Natural Park

ongoing production of crops in Manitoba.[4]

Considering the share of cropland (as can be seen in Figure 3), there is a general increase in the cropland trend in the study area from 2011 to 2021. There is a sharp decrease from the year 2015

[3] https://open.canada.ca/data/en/dataset/199e4ab6-832b-4434-ac39-e4887d7cc4e5/resource/5b1f0f6d-57f6-48dd-afcd-78a399db1877
[4] https://mli.gov.mb.ca/

to 2017, which, based on the information provided by the data source (Statistics Canada), is attributed to the unusually high amount of rain in Manitoba during those years. This led to the formation of numerous ponds and wet areas in the crop areas. Since the information is gathered based on satellite data, there is a possibility that these areas could not be accurately identified and classified as cropland, wetland, or water.

On the other hand, there is a general decrease in the share of habitats, which includes pasture, grassland, wetland, and Trees (Figure 4). Additionally, a slight increase in woodland and forest can be observed.

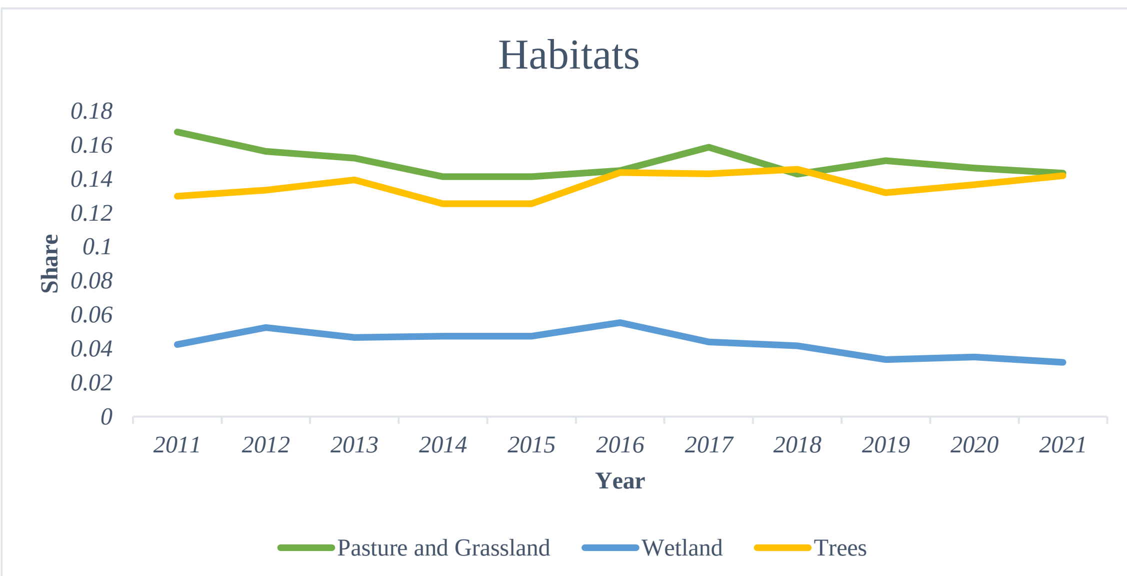

Figure 4. Average Share of Habitats in Parcels Neighbouring Riding Mountain Natural Park

As it shows in my independent variables, the parcel's physical characteristics are collected from the number of sources based on each specification. The soil cover data utilized in this study is sourced from the Manitoba Land Initiative website.[5] This dataset is accessible in the form of

[5] https://mli.gov.mb.ca/

polygon shape files corresponding to each municipality in Manitoba. The information encompassed in this data comprises details such as the slope and elevation of the land, soil salinity, the level of erosion, stoniness, and the agricultural capability class of the soils.

The Agricultural Capability Class (LCC) system, established by the Canadian Land Inventory (CLI), categorizes soils into seven classes, including a category for water.[6] The CLI's classification accommodates the diverse soils found in the region. The classes range from LCC 1 and 2, indicating soils with no significant limitations for farming, to LCC 3 and 4, representing soils with moderate limitations for agricultural production. Additionally, LCC 5, 6, and 7, along with the water category, denote soils deemed unsuitable for crop production. In alignment with the approach outlined in Lawley and Towe (2014), the seven LCC classes are condensed into three overarching categories for simplification: high agricultural productivity soils, comprising LCC 1 and 2; medium agricultural productivity soils, encompassing LCC 3 and 4; and low agricultural productivity soils, including LCC 5, 6, and 7, along with water.

To provide a clear summary of the data for descriptive purposes, I have systematically classified each parcel into three discrete categories.[7] This classification serves to help understand the distribution of cropland across different soil qualities. Specifically, parcels with an aggregate soil presence of 75 percent or more within classes 1, 2, 3, and 4 are designated as high capability parcels. Those falling within the range of 25 to 75 percent are categorized as medium capability, while parcels with less than 25 percent arable high soil quality are identified as low capability. This categorization allows for a detailed analysis of how cropland distribution varies with soil

[6] https://sis.agr.gc.ca/cansis/nsdb/cli/classdesc.html

[7] These discrete categories are assigned at the parcel level for descriptive purposes and are not the same as the categories used in the regression analysis that follows. The regression analysis uses within-parcel shares of land in the three soil capability categories.

quality. Subsequently, I conducted a comparative examination of cropland distribution among these parcel groups. The results are presented in Figure 5.

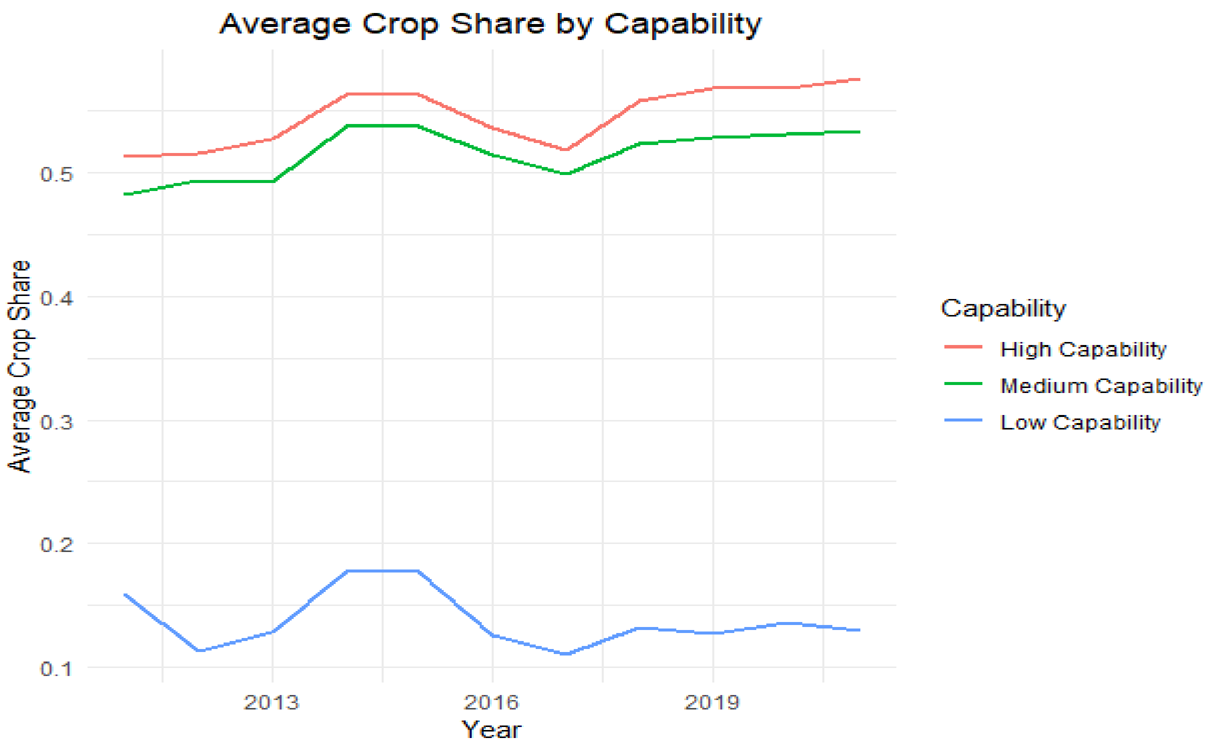

Figure 5. Average Crop Share of the Parcels with High, Medium, and Low Soil Capability

As depicted in figure 5, a discernible pattern emerges, illustrating an upward trajectory in the share of cropland within parcels characterized by superior soil quality. While there is a noteworthy increase in crop share for parcels with medium quality, the rate of ascent is comparatively more gradual than that observed in high-quality parcels. Upon comprehensive examination, a reduction is observed in the overall cropland share within parcels featuring lower soil quality. This observation leads to the conclusion that land conversion predominantly transpires in areas characterized by higher soil quality, underscoring a pronounced correlation between soil quality and cropland distribution within each parcel.

The presence of rock fragments on the soil surface or protruding above ground has a significant impact on soil utilization and management. The constraints imposed by these rock fragments are determined by factors such as their quantity, dimensions, and distribution across the surface. Consequently, the Manitoba Land Initiative (MLI) categorizes stoniness into five distinct categories, including a classification for non-applicable parcels. The categories range from non-stony, indicating no or very few stones that do not interfere with cultivation, to excessively stony, where the land surface is covered extensively with stones, hindering cultivation.

For soil salinity, defined as the soluble salt content in soil (Wang et al., 2014), MLI identifies four categories: non-saline, weakly saline, moderately saline, and strongly saline, along with a classification for not available parcels. Soil salinity poses limitations to plant growth due to the presence of soluble salts, which bind water more tightly than plants can extract, resulting in symptoms of drought despite relatively moist soil conditions.

Soil erosion, defined as the movement of soil from one area to another, leads to the removal of topsoil, reduction in soil organic matter, and disruption of soil structure. This, in turn, diminishes soil fertility and hampers air and water movement at the soil surface, ultimately reducing crop yield (AAFC). The categorization of erosion includes not eroded, slightly eroded, moderately eroded, and severely eroded, along with classifications for overblown and not available parcels.

Consistently, the same approach used for soil capability classes is applied to stoniness, salinity, and erosion, collapsing various categories. This results in three categories for stoniness, two for salinity, and two for erosion. For stoniness, the categories are defined as follows: 'Low' includes areas classified as non-stony and slightly stony; 'Medium' combines moderately stony and very stony; and 'High' encompasses exceedingly stony and excessively stony regions. For salinity, 'Low' is derived from non-saline and weakly saline areas, while 'High' includes moderately saline and strongly saline regions. In terms of erosion, 'Low' combines not eroded and slightly eroded areas, and 'High' aggregates moderately eroded and severely eroded regions.

It is essential to note that in this model, all soil characteristics are measured and utilized as shares to enhance comparability across different units of characteristics. This approach ensures a standardized basis for analysis, facilitating the meaningful comparison of diverse soil features.

The slope value in my data set represents the steepness of the land and centroid in percentage terms (meters vertical per 100 m horizontal). This percentage is calculated by taking the vertical rise of the slope (the height difference) over a given horizontal distance and then multiplying by 100 to get a percentage. For example, a slope value of 0.5% indicates that for every 100 units of horizontal distance, the land rises by 0.5 units vertically. This value is calculated as the mean slope steepness across the entire parcel.

Additionally, the consideration of crop share as the dependent variable complements this methodology. Using crop share as the dependent variable is because it directly reflects the proportion of land allocated to annual crops, which is influenced by soil quality and other factors. This alignment between the dependent variable and the soil characteristics being studied enables a more precise and meaningful analysis of how variations in soil quality impact land use decisions and agricultural productivity. The incorporation of shares in the model is advantageous for several reasons. Firstly, it is making comparisons fair regardless of the original measurement units of different soil characteristics (like stoniness, erosion, and salinity). This approach ensures that differences in soil characteristics are evaluated on a comparable basis. Secondly, the use of shares enhances the model's interpretability, as it emphasizes the relative contribution of each soil characteristic to the overall composition. This not only aids in simplifying the model but also provides a clearer understanding of the factors influencing crop share.

In this study, I systematically gathered diverse datasets from multiple sources to determine the optimal criterion for income or crop return. The data includes crop production measured in metric tonnes at the Census Agricultural Region level, total arable area reported in acres for these crops, and corresponding price data in dollars per metric tonne. To calculate the average revenue per acre, I multiplied the crop production by the price and divided the result by the total arable area, yielding the revenue per acre for each crop in every Census Agricultural Region.

To report the total crop return at the municipality level, I first needed to identify which municipalities fell within each of the 12 census agricultural regions mentioned in the production data. This data represents the southwestern part of the prairie province of Manitoba. Based on the Census of Agriculture by Statistics Canada, this region is considered as the agricultural region in Manitoba and based on our assimilation with our study area just agricultural regions 2, 3, 4, 6, and 7 was considered.[8] Information on the names of municipalities and census divisions within each region was sourced from the Manitoba Land Initiative and Census of Agriculture. I then computed the weighted average revenue for each municipality based on its presence in each agricultural region.

An alternative approach involved obtaining detailed data from the Manitoba Agriculture Service Corporation (MASC) at the municipality level. MASC, a Crown corporation established under

[8] https://www150.statcan.gc.ca/n1/en/pub/95-630-x/2022001/pdf/Prov46_CARCD_e.pdf?st=wcww6BZU

The Manitoba Agricultural Services Corporation Act, has been active since 1960, providing crop insurance, financial services, and various programs aimed at supporting rural communities in Manitoba.[9] Acre and yield per acre data for different crop varieties in each municipality are obtained from the MASC. By multiplying these figures and using the previously obtained price data, I calculated the weighted average revenue for each municipality, resulting in a more granular understanding of crop returns at the local level.

Weighted average per acre revenue (Z_{rt}) is calculated based on following formula:

$$(2) \quad Z_{rt} = \frac{\sum_{r=1}^{n=5} Y_{rt} P_t}{Total\ Acres}$$

where rt indicates the crops cultivated in the municipality r and at time t (including wheat, canola, soybean, corn, etc.), Y and P shows the yield and price (in nominal term) respectively.

The formula outlined in equation (2) summarizes the calculation of the weighted average per acre revenue (Z_{rt}). This dual-method approach contributes to a comprehensive assessment of crop revenue at both the agricultural region and municipality levels. Nevertheless, due to inconsistencies in data collection across municipalities during the study period (possibly arising from the inherent microscale of this data) and considering that there is no information for crops cultivated in less than 500 acres or in fewer than 3 farms (to retain producer anonymity), there were instances of missing data for certain primary crops in various municipalities for certain years. This data gap could potentially impact the reliability of the variable under consideration.

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9 https://masc.mb.ca

3.5. Descriptive Statistics

Summary statistics of the different land uses, income, and soil characteristics are presented in table 1. Across the entire study area, on average, less than one percent (0.8%) of each parcel is designated for developed areas. All habitats, encompassing shrubland, grassland, pasture, wetland, and forest, on average constitute 50 percent of each parcel; cropland alone accounts for nearly 50 percent of each parcel. As previously mentioned in this study, four distinct types of income are under consideration. However, the disparities between the averages of each income category are not substantial. On average, the income assessed by utilizing the top crops seeded for each municipality stands at $360.30 per acre. When broadening the scope to the top six crops seeded across the entire province for each municipality, the average experiences a slight increase, reaching $361.73 per acre. Notably, the income derived from canola, the predominant crop, registers at $401.64 per acre, affirming its status as the most extensively cultivated crop in the study area. Yet, when income is assessed at the agricultural region scale rather than the municipality level, the average for agricultural regions drops to $326.2. As it can be seen from the Table 1, the lower average of soils with higher capability compared to those with medium capability (approximately 65 percent of the soils are classified as either medium quality or low quality) suggests a prevalent composition of soils possessing moderate capability and, to a certain extent, lower quality within the study area. Conversely, the average composition indicates that a majority of areas within each parcel exhibit a higher prevalence of soil characteristics preferred for quality. Specifically, attributes such as lower stoniness, reduced salinity, and minimal erosion are considered. Notably, in our study area, nearly 95 percent of parcels showcase lower stoniness and less erosion, while 75 percent of each parcel demonstrates lower salinity. This suggests a predominant presence of soil conditions conducive to improved agricultural practices and underscores the positive quality of these key soil characteristics across the study area. It's worth mentioning that the average size of the parcels considered for this study is 158.51 acres, with the largest parcel being 661.67 acres.

Table 1. Descriptive Statistics

Variable	Mean.	Std. Deviation	Min	Max
Water	0.014	0.003	0.009	0.018
shrubland and grassland	0.212	0.022	0.182	0.260
urban/ developed/greenhouse areas	0.008	0.003	0.006	0.014
Pasture	0.087	0.021	0.052	0.131
Wetland	0.043	0.007	0.032	0.055
Cropland	0.499	0.020	0.470	0.520
forest and mixed wood	0.136	0.007	0.125	0.146
Income	360.300	65.224	193.954	538.913
$\text{Income}^{\text{Top6}}$	361.732	62.322	186.407	536.238
$\text{Income}^{\text{Canola}}$	401.639	72.207	224.790	580.999
$\text{Income}^{\text{Ag Regions}}$	326.278	49.846	233.594	428.222
$\text{Capability}_{\text{High}}$	0.349	0.372	0	1
$\text{Capability}_{\text{Medium}}$	0.379	0.397	0	1
$\text{Capability}_{\text{Low}}$	0.271	0.265	0	1
Slope (percentage)	4.450	6.788	0	85
Elevation (meter)	423.867	125.591	242	698

$Salinity_{Na}$	0.046	0.142	0	1
$Salinity_{Low}$	0.949	0.150	0	1
$Salinity_{High}$	0.004	0.051	0	1
$Stonniness_{Na}$	0.030	0.119	0	1
$Stoniness_{Low}$	0.765	0.374	0	1
$Stoniness_{Medium}$	0.204	0.367	0	1
$Stoniness_{High}$	0.001	0.032	0	1
$Erosion_{Na}$	0.031	0.121	0	1
$Erosion_{Low}$	0.952	0.144	0	1
$Erosion_{High}$	0.017	0.081	0	1
Size of the Parcels	151.326	49.155	40	661.67
Observation		375089		

Chapter 4: Results and Discussions

In this chapter, I present the results of the analysis and provide a thorough discussion of these results. The chapter also explores the various models and robustness checks conducted to evaluate the sensitivity of the results.

4.1. Results from the Econometric Models

I begin by running a series of regression models, following equation (1) as presented in Chapter 3. As shown in table 2, I obtain my regressions across six different models. Model 1 establishes the baseline with municipality and time fixed effects. In model 2, I added an interaction of municipality and time fixed effects to the model 1. Model 3 includes an interaction between municipality and time trend, in addition to the fixed effects. Models 4 to 6 are similar to models 1 to 3 but include a time trend variable.

Based on the results from model 1, the observed coefficients align logically with theoretical expectations and past studies. I find positive and significant effects from variables capturing the effects of soil characteristics of parcels on cropland share.

The results for the slope variable reveal a negative correlation with cropland share, indicating that lands with higher slopes are less likely to convert to cropland. There is a slight decrease in the share of cropland per one percent increase in the slope of the soil. An additional percent of slope, for example from 2% to 3% slope, leads to a 0.0018% decrease in share of cropland. This negative correlation is statistically significant at the 1% level, highlighting the challenges associated with converting lands with high slopes for agricultural purposes. These challenges are likely due to the increased difficulty and costs associated with farming on steep terrain. This information provides insights into the topographical factors influencing cropland dynamics within the studied regions.

However, elevation has a positive impact on the share of cropland; a one metre increase in elevation increase cropland share by 0.0013% with a significance level of 1%.

Moving on to the salinity, the coefficient for low salinity is positive and statistically significant at 1%, indicating that low salinity in soil contributes to an increase in cropland share. Specifically, a one-percent increase in low salinity leads to a 0.164% increase in cropland share. This suggests that lower salinity levels make the soil more suitable for agriculture, likely because high salinity can inhibit plant growth and reduce crop yields.

Examining low stoniness, the coefficient is positive (0.299) and highly significant at the 1% level, suggesting that parcels with low stoniness experience a substantial increase in cropland share. This is likely because soils with fewer stones are easier to till and plant, thus more attractive for agricultural use. Medium stoniness also shows a positive and significant relationship, though the impact is less compared to low stoniness (0.102 versus 0.299). This implies that while low stoniness has a significant effect on cropland share, medium stoniness also contributes to a moderate increase, indicating that some stones may be manageable but still present a challenge compared to low stoniness.

Regarding the erosion variable, the coefficient for less eroded parcels is 0.103 and significant at the 1% level, indicating that areas with low erosion levels experience a considerable increase in cropland share. This can be explained by the fact that less eroded soil retains more nutrients and organic matter, which are crucial for crop productivity. Hence, these areas are more favorable for agricultural purposes. Overall, these results highlight the importance of soil characteristics in determining the suitability of land for agricultural use. Improvements in soil quality, such as reducing salinity, stoniness, and erosion, can significantly enhance the potential for cropland expansion.

To summarize, the results from model 1 reveal different factors influencing cropland distribution. Elevation, stoniness, and erosion levels play pivotal roles, each with varying degrees of impact. As we progress through subsequent models, the introduction of additional fixed effects and interaction terms will further refine our understanding of the relationships within the agricultural regions under study. The progression from model 1 to model 6 unveils an understanding of the factors influencing cropland distribution within the studied agricultural regions.

As the models' progress, similar results can be seen from model 1 to 3 for all the soil characteristics. However, from model 4 to 6 more fluctuations in results can be seen. The introduction of topographical factors in model 4 sheds light on the relationship between elevation, slope, and cropland dynamics. The negative and significant coefficient for slope across all models indicates that lands with higher slopes are less inclined to undergo cropland conversion. Elevation initially exhibits a positive and significant coefficient, but it introduces a more nuanced pattern in subsequent models, particularly when interacted with the time trend. This implies an interaction between elevation and cropland distribution, highlighting its increased sensitivity to time.

In models 4 to 6, where soil characteristics are interacted with the time trend, there is a noticeable alteration in the significance levels. Specifically, low salinity, low stoniness, medium stoniness, and low erosion exhibit variations in their coefficients and standard errors, leading to changes in their significance.

The significant decrease in the level of significance or the lack of significance observed in these soil characteristics when interacted with the time trend highlights the importance of temporal considerations in understanding their impact on cropland distribution. This suggests that the influence of low salinity, low stoniness, medium stoniness, and low erosion on cropland distribution is subject to temporal dynamics, which may be attributed to evolving environmental conditions, land management practices, or other temporal factors.

However, estimates of the impact of income and soil capability on cropland share are derived from marginal effects (table 3). This approach is essential because the main table includes interaction terms between income and soil capabilities, complicating direct interpretation. The marginal effects estimate the average change in cropland share for a unit increase in income at specific levels of soil capability. This method offers a clearer and more precise understanding of how income and soil capabilities jointly influence cropland share.

Beginning with the municipal and time fixed effects in model 1, the positive and statistically significant coefficients for income emphasize the robust relationship between income and cropland share. This positive correlation remains consistent across subsequent models, indicating the stability of this factor.

Table 2. Baseline models with fixed effects interactions

Model	*1*		*2*		*3*		*4*		*5*		*6*	
variables	*Coefficient*	*St. Err*	*Coefficient*	*St. Err*	*Coefficient*	*St. Err*	*Coefficient*	*St. Err*	*Coefficient*	*St. Err*	*Coefficient*	*St. Err*
Slope	-1.80E-03***	8.17E-05	-1.81E-03***	8.17E-05	-1.81E-03***	8.18E-05	-0.102**	4.80E-02	-0.110**	5.20E-02	-0.112**	5.20E-02
Elevation	1.30E-04***	1.33E-05	1.28E-04***	1.33E-05	1.28E-04***	1.33E-05	1.00E-03	3.00E-03	-0.025***	8.00E-03	-0.026***	8.00E-03
$Salinity_{NA}$	-1.50E-02	2.70E-02	-2.00E-02	2.70E-02	-1.90E-02	2.70E-02	77.097***	1.80E+01	47.307***	1.78E+01	47.038***	1.80E+01
$Salinity_{Low}$	0.164***	9.00E-03	0.162***	9.00E-03	0.163***	9.00E-03	-7.08E+00	5.77E+00	6.31E+00	5.88E+00	6.81E+00	5.90E+00
$Stonniness_{NA}$	0.267***	2.20E-02	0.264***	2.20E-02	0.265***	2.20E-02	1.48E+01	1.46E+01	1.40E+01	1.47E+01	1.44E+01	1.47E+01
$Stoniness_{Low}$	0.299***	7.00E-03	0.299***	7.00E-03	0.299***	7.00E-03	-1.56E+00	4.96E+00	12.462**	5.23E+00	12.705**	5.16E+00
$Stoniness_{Medium}$	0.102***	7.00E-03	0.102***	7.00E-03	0.102***	7.00E-03	-4.79E+00	4.96E+00	7.80E+00	5.23E+00	7.97E+00	5.16E+00
$Erosion_{NA}$	-2.60E-02	2.10E-02	-2.30E-02	2.10E-02	-2.30E-02	2.10E-02	-28.109**	1.38E+01	-1.06E+01	1.38E+01	-1.07E+01	1.39E+01
$Erosion_{Low}$	0.103***	2.60E-02	0.100***	2.50E-02	0.100***	2.50E-02	71.132***	1.70E+01	35.623**	1.69E+01	35.233**	1.70E+01
$Income^{Ag\ Regions}$	1.13E-04*	6.62E-05	0.0088***	8.65E-04	2.68E-04***	7.74E-05	1.17E-04*	6.91E-05	0.0096***	1.11E-03	2.25E-04***	7.87E-05
$Capability_{High}$	0.375***	1.20E-02	0.377***	1.40E-02	0.371***	1.30E-02	0.371***	1.40E-02	0.357***	1.50E-02	0.350***	1.50E-02
$Capability_{Medium}$	9.00E-03	1.20E-02	0.078***	1.40E-02	0.068***	1.40E-02	2.30E-02	1.50E-02	0.062***	1.50E-02	0.052***	1.50E-02
$Income * Capability_{High}$	7.74E-04***	3.87E-05	7.69E-04***	4.33E-05	7.88E-04***	4.31E-05	7.85E-04***	4.55E-05	8.32E-04***	4.92E-05	8.54E-04***	4.89E-05
$Income * Capability_{Medium}$	7.72E-04***	3.95E-05	5.62E-04***	4.57E-05	5.91E-04***	4.55E-05	7.30E-04***	4.66E-05	6.09E-04***	4.87E-05	6.42E-04***	4.85E-05
R^2	0.42		0.43		0.43		0.43		0.43		0.43	
Observations	375,089		375,089		375,089		375,089		375,089		375,089	
Municipality Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Time Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Municipality x Time Fixed Effect	No		Yes		No		No		Yes		No	
Municipality x Time Trend	No		No		Yes		No		No		Yes	
Variable Time Trend	No		No		No		Yes		Yes		Yes	

Notes: Asterisks (***, **, *) denote statistical significance at 1%, 5%, and 10% respectively.

While the main table coefficients represent the direct percentage change in cropland share resulting from a change in income, the margins table coefficients reflect the probability that cropland share will increase with a one-unit increase in income, holding other factors constant. Similarly, the income margins at high capability and medium capability maintain positive and highly significant coefficients, indicating a positive relationship between income and cropland share within different levels of soil capability.

Turning to the soil capability margins, high capability and medium capability consistently exhibit positive and highly significant coefficients, mirroring the patterns observed in the main table. These coefficients underscore the direct relationship between high and medium soil capability and cropland share.

The introduction of interaction terms in the margins table (table 3), such as income margin at high capability and income margin at medium capability, further enhance the analysis by highlighting the varying impact of income across different levels of soil capability. The analysis of income margins across different soil capabilities reveals that the effect of income on cropland share is highly dependent on soil quality. Higher income levels have a more substantial impact on high-quality soils, promoting their conversion to cropland. Medium-quality soils show a moderate response, while low-quality soils exhibit minimal responsiveness to income changes. These findings highlight the critical role of soil quality in agricultural land use decisions and underscore the importance of targeting economic incentives to maximize agricultural productivity.

To be specific, At the mean values of other variables, a one dollar increases in income per acre results in a 0.0677% increase in cropland share. This effect is statistically significant at the 1% level. To provide a more meaningful perspective, consider the average crop revenue of $326.278 per acre. A 5% increase in this revenue results in an additional $16.3139 per acre. Applying the established relationship, this increase corresponds to a 1.1 percentage point increase in cropland share. This example underscores how even modest revenue increases can impact land use decisions, illustrating the sensitivity of cropland allocation to changes in revenue. For the soil capabilities, parcels with high and medium soil capability have 62.7 and 26.1 percentage points higher cropland share compared to the reference category (low soil capability) respectively. Related to the interaction of income and soil capabilities, for parcels with high soil capability, a one-dollar increase in income per acre results in a 0.0887% increase in cropland share and for parcels with medium soil capability, a one-dollar increase in income per acre results in a 0.0886% increase in cropland share. These effects are statistically significant at the 1% level.

Adding the municipality and time fixed effect interaction to the model (model 2) has a more significant effect on income and soil capabilities because of a larger coefficient for income, as well as a slight larger coefficient for high soil capability compared to model 1.

To get into more details, the persistent positive coefficients for high soil capability indicate the crucial role of high-quality soils in driving cropland efficiency. This consistency suggests a strong and direct relationship. Specifically, parcels with high soil capability have a 62% higher cropland share compared to those with lower soil capabilities. The interaction terms capture the dynamic relationship between soil capability and cropland share, reflecting changes in agricultural technology, economic conditions, and land management practices that enhance the productivity and suitability of medium capability soils over time. This suggests that the dynamics of cropland distribution are linked to the quality of soils classified as medium capability, and their influence becomes more significant when considering temporal factors.

Furthermore, the interactive effects of municipality fixed effect with time fixed effect or time trend underscore the nature of the relationship between soil capabilities and land use changes. The heightened significance in these models implies that the impact of medium capability soils on cropland distribution is not static but evolves over time, potentially influenced by various external factors. Overall, marginal effects demonstrate that income and soil capability jointly influence cropland share, with higher soil quality enhancing the positive effect of income. These insights emphasize the importance of considering interactions and fixed effects to accurately capture the dynamics of land use changes.

Table 3. Marginal Effects for Baseline models with fixed effects interactions

Model	1		2		3		4		5		6	
variables	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*
Income $_{Margin\ (at\ Mean)}$	6.77E-04***	6.15E-05	0.0093***	2.00E-03	7.68E-04***	7.20E-05	6.69E-04***	6.22E-05	0.010***	1.00E-03	7.67E-04***	7.20E-05
Capability$_{High}$	0.627***	2.00E-03	0.628***	2.00E-03	0.628***	2.00E-03	0.628***	2.00E-03	0.628***	2.00E-03	0.628***	2.00E-03
Capability$_{Medium}$	0.261***	2.00E-03	0.261***	2.00E-03	0.261***	2.00E-03	0.261***	2.00E-03	0.261***	2.00E-03	0.261***	2.00E-03
Income $_{Margin\ (at\ high\ capability)}$	8.87E-04***	6.53E-05	0.0096***	2.00E-03	1.06E-03***	7.57E-05	9.02E-04***	6.57E-06	1.04E-03***	1.10E-03	0.0011***	7.62E-05
Income $_{Margin\ (at\ medium\ capability)}$	8.86E-04***	6.35E-05	0.0094***	2.00E-03	8.70E-04***	7.48E-05	8.48E-04***	6.59E-05	1.02E-01***	1.10E-03	8.67E-04***	7.49E-05
Income $_{Margin\ (at\ low\ capability)}$	1.13E-04***	6.62E-05	0.0088***	2.00E-03	2.68E-04***	7.74E-05	1.17E-04***	6.91E-05	9.58E-03***	1.10E-03	2.25E-04***	7.87E-05
Municipality Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Time Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Municipality x Time Fixed Effect	No		Yes		No		No		Yes		No	
Municipality x Time Trend	No		No		Yes		No		No		Yes	
Variable Time Trend	No		No		No		Yes		Yes		Yes	

Notes: Asterisks (***, **, *) denote statistical significance at 1%, 5%, and 10% respectively.

It is worth mentioning that the results discussed earlier derived from income levels in CARs. However, I have also measured income in several other ways using municipality data, focusing on i) the six crops with the highest cropland share in the entire province, and ii) income earned from canola, which is the crop with the highest share of arable lands in Manitoba. However, there are some limitations in each of these methods of income calculation that can impact the reliability of the results. For instance, the data for price and yield for municipalities in our study area is not fully available, meaning that data in municipalities with fewer than three producers or less than 500 acres has not been included. Additionally, for the specific income crops calculation, it is necessary to have data for each year throughout the study period for each crop. However, due to the reliance on census agricultural data, which is collected every four years, comprehensive data for all years is not available.

Comparing the results, however, indicates that signs and values for the soil characteristics show consistency in the results as they are not significantly changing. Moreover, by looking at the marginal effects, the sign and values for the interaction between income and soil capabilities also shows the reliable sign in most of the models for different income measurements. A primary observation is the differing signs of income effects. In many models, the coefficient for income displays a predominantly negative sign. This coefficient represents the marginal effect on the omitted land category (low soil capability). In models incorporating interactions between municipality fixed effects and time fixed effects or time trends, a positive relationship between income and cropland share becomes apparent. A crucial observation arises when examining the marginal effects of various income measurements on the share of cropland, revealing predominantly positive signs across most models. This discrepancy in signs between the average coefficients and marginal effects can be attributed to the interaction of income with other variables in the model. While the overall relationship between income and cropland share, as indicated by the coefficients, may appear negative on average, the positive signs in the margins underscore the importance of considering the isolated effect of income when other variables are held at their mean levels.

4.2. Results From Land Conversion Predictions

In this section, I will introduce parcels at risk of conversion in each municipality and explore the relationship between at-risk parcels and those that have already been converted. Additionally, I will assess whether the potentially at-risk parcels are already under conservation.

To begin, it is necessary to explain how a parcel at risk of conversion is defined. A parcel is deemed at risk of conversion when the predicted share of cropland is higher than the observed or actual share of cropland. In other words, when the predicted share of cropland is higher than the actual share, it indicates that those parcels have a potential probability of converting to cropland to reach the predicted share. This assessment is made on an annual basis. Specifically, a parcel is considered at risk if, for any given year within the dataset, the predicted share exceeds the observed share. It needs to be consistent across all years, so a parcel is classified as at risk of conversion if its predicted share is consistently higher than its actual share for all years in the dataset. This approach allows us to capture potential risks of conversion when they are at-risk over all years. This determination is achieved by utilizing the coefficients of the explanatory variables, which are reintroduced into the model to predict the new share of cropland. The comprehensive results regarding the at-risk parcels in each municipality can be found in table 4.

Table 4. At-Risk Parcels in Each Municipality

Municipality	*Number of at-risk parcels*	*% of municipality parcels at risk*	*Total area (acres) of at-risk parcels*	*% of municipal area at risk*	*Current % of parcel in cropland on at-risk parcels*	*% of at-risk parcels vulnerable to further conversion*
114	54	48	37154.37	82	71	11
359	345	39	51285.81	38	28	10
118	694	32	118525.7	32	24	8
142	647	34	102183.9	33	25	8
200	762	30	115366	30	23	8
143	769	49	145043.7	49	41	7
147	295	40	42997.86	40	33	7
170	296	31	41760.29	30	23	7
609	183	31	20905.86	31	25	7
181	540	24	79391.06	24	19	6
182	648	30	97506.76	30	24	6
323	254	19	39116.83	19	13	6
403	646	26	97983.7	26	20	6
443	233	27	34021.59	27	21	6
101	447	27	67946.65	28	23	5
132	243	22	33943.77	22	17	5
159	239	22	34257.36	22	17	5
353	74	21	11338.02	22	17	5
445	228	25	34453.13	25	20	5
126 &154	341	37	57040.23	30	26	4
183	301	22	43828.23	21	17	4
601	1735	59	257178.2	59	55	4
107	331	21	54389.09	19	16	3
124	158	18	35793.79	18	15	3
331	145	19	22739.11	19	16	3

Notes: The third column represents the percentage of the total parcels in each municipality that are considered at risk, as indicated in the second column. The fifth column shows that the acreages of land under risk in the fourth column is what percentage of the total acreages in each municipality. The sixth column shows what percentage of areas under risk of conversion in the fifth column already converted to cropland. Percentage of potentially converted areas (last column) shows the difference between percentage of total at-risk parcels' areas and the percentage of those at-risk parcels' areas already converted to cropland (column five – column six).

As indicated in table 4, municipalities 114 and 359 exhibit a noteworthy trend, with over 10 percent of their areas at risk of conversion, signifying a higher share of their total area being susceptible to conversion. Meanwhile, municipalities 601, 143, and 118 stand out as having the greatest acreage at-risk of conversion. Additionally, municipalities 601, 143, and 200 lead in terms of the highest number of parcels at-risk of conversion.

To gain a better understanding of parcels with the highest priority and to provide conservation agencies with focused insights on specific parcels in particular municipalities, we define parcels at the highest risk of conversion. Initially, we determine the minimum difference between the predicted share and the actual share for each parcel by considering the smallest share difference over the entire 11-year period. This approach helps us come up with one number for each parcel over the period, making the comparison easier. This method provides insight into the minimum possible conversion for each parcel during the study period. Subsequently, we rank each parcel based on this minimum difference, arranging them from largest to smallest. Finally, we identify the top decile of parcels as the highest-risk parcels, considering those with the highest minimum share differences over the study period. These parcels are predicted to be at risk in each of the 11 years of the study period. This methodology aims to offer a comprehensive perspective that aids conservation agencies in directing their attention towards parcels most susceptible to conversion.

Table 5. Parcels and Acres of High-Risk Municipalities

Municipality	Municipality identification number	Number of Parcels at High Risk of Conversion	Share of Municipality Acreage at High Risk of Conversion
Gilbert Plains	323	74	1.48
Riding Mountain West	181	110	0.96
Minto-Odanah	159	42	0.89
Rossburn	353	8	0.81
Westlake-Gladstone	200	112	0.73
Riverdale	443	33	0.72
Ste. Rose	359	57	0.70
Dauphin	118	114	0.63
Yellowhead	183	40	0.63
Prairie View	403	89	0.63
Oakview	107	50	0.62
Elton	124	22	0.61
Grandview	132	27	0.52
Russell-Binscarth	445	28	0.50
Glenella-lansdowne	142	79	0.48
Hamiota	331	12	0.40
Mccreary	147	22	0.38
Rosedale	170	22	0.35
Harrison Park	609	11	0.27
Ellice-Archie	101	28	0.26
Roblin	182	31	0.22
Lakeshore	143	33	0.18
Ethelbert & Mossey River	126 & 154	16	0.16

As evident from the data presented in table 5, seven municipalities (323, 181, 159, 353, 200, 443, and 359) face a substantial risk of conversion, with at least 0.70 percent of their respective areas at the highest risk (see figure 8). While this percentage might appear modest, the significance amplifies when considering the diverse range of areas, spanning from 618 to almost 9200 acres. Municipalities 118, 200, 181, 403, 142, and 323 emerge as particularly vulnerable, boasting the highest number of parcels (each with a minimum of 70 parcels) at the highest risk of conversion. Delving into the specifics provided in the table, it becomes evident that Municipality 323 leads with 74 parcels at risk, constituting 1.48 percent of its acreage. Following closely, Municipality 181 exhibits 110 parcels at risk, accounting for 0.96 percent of its total acreage.

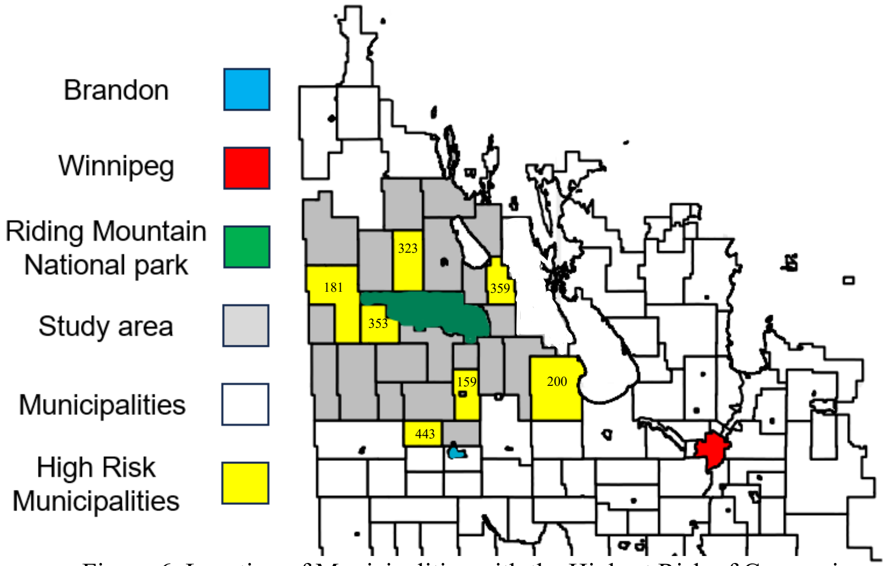

Figure 6. Location of Municipalities with the Highest Risk of Conversion

Beyond these highlighted municipalities, others such as 353, 200, 443, and 359 also showcase a considerable share of acreage at risk, underscoring the widespread nature of the challenge. Despite seemingly modest percentages, the cumulative impact on areas ranging from 618 acres to almost 9,200 acres cannot be underestimated.

In addition to parcel numbers, it is crucial to recognize the urgency of addressing the issue and implementing targeted conservation efforts, especially in the regions dominated by municipalities 118, 200, 181, 403, 142, and 323. Understanding the spatial distribution and magnitude of the problem is imperative for developing effective strategies to mitigate the risks associated with ongoing land conversion processes.

With a comprehensive understanding of the municipalities in our study region at high-risk of conversion, it is essential to explore those that have implemented conservation measures. Among the municipalities facing the highest risk of conversion, Riding Mountain West (181), holding one of the highest area shares at risk, has secured only 1.102 percent in conservation. Examining the remaining high-risk municipalities only 7 out of 23 municipalities got some protections with either easement or fee simple (see table 6). Harrison Park, Ellice-Archie and Roblin have received the highest protection share areas, with conservation percentages of 5.585 percent, 1.412 percent and 1.572 percent, respectively. This highlights the proactive conservation efforts in these specific regions, demonstrating the potential for successful preservation despite the prevailing risks of land conversion.

Table 6. Protected Municipalities

Municipality	Municipality identification number	Number of Protected Parcels	% of Acreage Protected
Riding Mountain West	181	18	1.102
Dauphin	118	3	0.130
Yellowhead	183	2	0.297
Grandview	132	5	0.522
Harrison Park	609	18	5.585
Ellice-Archie	101	11	1.418
Roblin	182	24	1.572
Lakeshore	143	3	0.096

Notes: Percentage of acreage protected refers to the share of land in each municipality that is already under protection through either easement contract or fee simple by different conservation agencies.

Chapter 5: Conclusions and Recommendations

Human activities, notably the expansion of agriculture and the influence of climate change, pose substantial threats to various ecosystems, including grasslands, wetlands, and forests. Studies indicate that more than fifty percent of the wetlands within the North American Prairie Pothole Region (PPR) have experienced degradation or harm since the period of European settlement. Additionally, considerable challenges confront wetlands and waterfowl habitats, particularly within Canada's western grain belt. In this regard, the conservation of habitats and controlling land use changes is crucial.

The main objective of this study was examining the influence of physical and economic factors of wetland and grassland to cropland in the agricultural production region neighboring Riding Mountain National Park. This study also predicted which parcels in which municipalities are at highest risk of conversion. Given the extensive ecologically significant natural areas that enjoy robust support from local communities and conservation agencies, coupled with the advantages derived from a balanced mix of recreational activities, ecotourism endeavors, agricultural practices, and responsible resource extraction industries, the municipalities surrounding RMNP were deemed a valuable focal point for this study. To do this, the study employed regression-based method – namely land use share model. Took advantage of valuable datasets encompassing various land uses and the physical attributes of different parcels, alongside historical data on prices and yields of diverse crop types, to construct a comprehensive dataset. Using these resources, I constructed variables that accounted for the physical characteristics of the parcels and measuring the weighted average per acre crop revenue as these were some of the factors that literature suggests influence land use conversion.

I conducted an estimation to measure the impact of the physical characteristics of lands and the revenue generated from each cropland on the proportion of cropland, providing an understanding of the factors influencing land use conversion. Furthermore, leveraging the coefficients derived from the model, I developed a predictive model to identify parcels with characteristics posing a higher risk of conversion. To acknowledge this study, there is not any other studies that use a land use change share model to assess the impact of an actual policy by looking back on the past years performance of conservation programs such as Fee Simple and Easement in lands neighboring Riding Mountain National Park. Additionally, this study introduces a novel approach by predicting the cropland share of each parcel based on its characteristics, offering insights into identifying parcels at the highest risk of conversion.

Prior research has delved deeply into comprehending the intricate landscape of land use conversion policies, encompassing zoning regulations, taxation mechanisms, conservation reserve programs, and easement contracts. These studies have contributed valuable insights into the land use share model, utilizing parcel-level data to discern the impact of landowners' decisions in transitioning their lands from one use to another. These analyses consider factors such as net returns to alternative uses and the physical characteristics of the land that influence land use decisions. Moreover, there is evidence of predicting future land use changes with precision, underscoring the necessity for advanced modeling techniques driven by economic indicators, population dynamics, and environmental factors.

To establish the objective of this study, I initially examined various physical characteristics and economic factors to understand their impact on cropland share. The findings align closely with both my expectations and previous literature. The land use share model indicates a positive correlation between crop revenue and cropland share. Additionally, income has a more significant influence on cropland share for parcels with higher soil productivity compared to those with medium soil productivity. Geophysical factors also play a crucial role in influencing land use changes, revealing a positive relationship between cropland share and parcels with less erosion, fewer stones, gentler slopes, and lower salinity.

This study also predicts the parcels at the highest risk of conversion. By examining the minimum difference for each parcel, considering the smallest share difference over the entire 11-year period, the top decile of parcels, which includes those with the highest minimum share differences throughout the study period, is identified as the highest-risk category. Almost all municipalities have some parcels at the highest risk of conversion, particularly municipalities numbered 118, 200, and 181, each having more than 100 parcels in between top tire of parcels with the highest risk. Although easement policies are employed to protect habitats surrounding Riding Mountain National Park, the majority of habitat in this area require more attention. Consequently, there is a need for further improvement by expanding easement and fee simple coverage in these municipalities. The outcomes of this study provide a valuable tool for conservation agencies, aiding in the efficient allocation of their time and budget. This tool can assist them in focusing attention on parcels nearing conversion, facilitating the prioritization of municipalities that require protection before facing potential destruction.

However, there are some limitations to this proposed study. Limitations to this study begins with the assumption made in my model. The ecological benefits are not factored into the assessment of conversion risk. Moreover, this study does not consider the cost-benefit approach which can be used to find optimal conservation choices and strategies.

Another potential limitation within this study is related to the nature of the data. As in this research I used remotely sensed data, despite the launch of new satellites each year that have better resolution and a variety of sensors, new sources of error will inevitably emerge alongside the potential to reveal dynamics that were previously unknown. One of the errors that needs to be considered is "misclassification error" which causes inconsistent parameter estimates (Alix-Garcia and Millimet, 2022). Misclassification error is phenomenon of observations of land-use being classified incorrectly and causes mapped land-use to differ from true land-use (Olofsson et al., 2013; Sadler and Rashford, 2018). However, by looking deep into different studies, I realized that although misclassification errors are named as a potential error that can affect the results of the study, in almost all the studies (except a few studies like Alix-Garcia and Millimet (2022) and Sadler and Rashford (2018) which have examined hypothetical policy tools), it has been ignored by the researchers.

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Appendix

Table 7. Marginal Effects for the model of the regular income with fixed effects interactions

Model	*1*		*2*		*3*		*4*		*5*		*6*	
Independent variables	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*
Income $_{Margin\ (at\ Mean)}$	1.93E-04***	2.51E-05	-0.016***	2.00E-03	3.42E-04***	3.66E-05	1.99E-04***	2.51E-05	-1.43E-02***	2.00E-03	3.41E-04***	3.66E-05
Capability$_{High}$	0.627***	2.00E-03	0.626***	2.00E-03	0.626***	2.00E-03	0.627***	2.00E-03	0.626***	2.00E-03	0.626***	2.00E-03
Capability$_{Medium}$	0.265***	2.00E-03	0.264***	2.00E-03	0.263***	2.00E-03	0.264***	2.00E-03	0.264***	2.00E-03	0.264***	2.00E-03
Income $_{Margin\ (at\ high\ capability)}$	3.29E-04***	2.85E-05	-0.016***	2.00E-03	5.27E-04***	3.98E-05	3.48E-04***	2.92E-05	-1.41E-02***	2.00E-03	5.31E-04***	4.01E-05
Income $_{Margin\ (at\ medium\ capability)}$	3.55E-04***	2.99E-05	-0.016***	2.00E-03	4.25E-04***	4.03E-05	3.71E-04***	3.08E-05	-1.42E-02***	2.00E-03	4.26E-04***	4.04E-05
Income $_{Margin\ (at\ low\ capability)}$	-2.07E-04***	3.08E-05	-0.016***	2.00E-03	-1.30E-04***	4.14E-05	-1.71E-04***	3.17E-05	-1.47E-02***	2.00E-03	-2.16E-05***	4.21E-05
Municipality Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Time Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Municipality x Time Fixed Effect	No		Yes		No		No		Yes		No	
Municipality x Time Trend	No		No		Yes		No		No		Yes	
Variable Time Trend	No		No		No		Yes		Yes		Yes	

Table 8. Marginal Effects for the model of the top six crops income with fixed effects interactions

Model	*1*		*2*		*3*		*4*		*5*		*6*	
Independent Variables	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*
Income $_{Margin\ (at\ Mean)}$	2.09E-05***	3.48E-05	-2.13E-04***	6.66E-05	2.58E-04***	3.99E-05	3.58E-05***	3.51E-05	-2.21E-04***	8.59E-05	2.58E-04***	4.00E-05
Capability$_{High}$	0.628***	2.00E-03	0.627***	2.00E-03	0.627***	2.00E-03	0.627***	2.00E-03	0.628***	2.00E-03	0.627***	2.00E-03
Capability$_{Medium}$	0.264***	2.00E-03	0.263***	2.00E-03	0.263***	2.00E-03	0.263***	2.00E-03	0.264***	2.00E-03	0.263***	2.00E-03
Income $_{Margin\ (at\ high\ capability)}$	1.73E-04***	3.75E-05	3.86E-07***	6.94E-05	3.05E-04***	4.23E-05	2.03E-04***	3.81E-05	2.13E-04***	9.09E-05	4.81E-04***	4.34E-05
Income $_{Margin\ (at\ medium\ capability)}$	1.74E-05***	3.65E-05	-1.51E-04***	6.66E-05	4.74E-04***	4.32E-05	1.50E-04***	3.80E-05	-2.34E-04***	8.62E-05	3.07E-04***	4.23E-05
Income $_{Margin\ (at\ low\ capability)}$	-3.89E-04***	4.21E-05	-5.73E-04***	7.19E-05	-8.43E-05***	4.68E-05	-3.40E-04***	4.34E-05	-2.34E-04***	8.62E-05	-9.69E-05***	4.77E-05
Municipality Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Time Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Municipality x Time Fixed Effect	No		Yes		No		No		Yes		No	
Municipality x Time Trend	No		No		Yes		No		No		Yes	
Variable Time Trend	No		No		No		Yes		Yes		Yes	

Table 9. Marginal Effects for the model of the Canola income with fixed effects interactions

Model	*1*		*2*		*3*		*4*		*5*		*6*	
variables	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*	*Margin*	*St. Err*
$Income_{\text{Margin (at Mean)}}$	9.88E-05***	3.18E-05	-0.017***	2.00E-03	3.80E-04***	3.78E-05	1.26E-04***	3.21E-05	-0.015***	2.00E-03	3.80E-04***	3.78E-05
$Capability_{High}$	0.627***	2.00E-03	0.626***	2.00E-03	0.626***	2.00E-03	0.629***	2.00E-03	0.626***	2.00E-03	0.626***	2.00E-03
$Capability_{Medium}$	0.262***	2.00E-03	0.261***	2.00E-03	0.261***	2.00E-03	0.262***	2.00E-03	0.261***	2.00E-03	0.261***	2.00E-03
$Income_{\text{Margin (at high capability = 1)}}$	2.37E-04***	3.32E-05	-0.017***	2.00E-03	5.73E-04***	4.00E-05	2.77E-04***	3.43E-05	-0.015***	2.00E-03	5.76E-04***	4.02E-05
$Income_{\text{Margin (at medium capability = 1)}}$	1.69E-04***	3.41E-05	-0.017***	2.00E-03	3.44E-04***	4.05E-05	1.47E-04***	3.48E-05	-0.015***	2.00E-03	3.43E-04***	4.05E-05
$Income_{\text{Margin (at low capability = 1)}}$	-1.77E-04***	3.78E-05	-0.017***	2.00E-03	1.83E-04***	4.28E-05	-9.89E-04***	3.91E-05	-0.015***	2.00E-03	1.79E-04***	4.36E-05
Municipality Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Time Fixed Effect	Yes		Yes		Yes		Yes		Yes		Yes	
Municipality x Time Fixed Effect	No		Yes		No		No		Yes		No	
Municipality x Time Trend	No		No		Yes		No		No		Yes	
Variable Time Trend	No		No		No		Yes		Yes		Yes	